Lighting at the End of the Tunnel

The Design of Adaptive and Intelligent Lighting for an Underground Workspace

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ABSTRACT

Callio has been established to manage the rehabilitation of Pyhäsalmi Mine into a world-class business and research underground facility. The reuse of Pyhäsalmi Mine serves as a backdrop for studying the effects of artificial light in an underground workspace. This provides a rationale for a hypothesis respecting the lighting environment as affecting the physiological and psychological state of people working in environments with restricted exposure to natural light. Although the current lighting infrastructure may be sufficient for mining operations, it is questionable that the visual and non-visual lighting requirements of the future users of the deep underground facility can be fulfilled under the existent lighting conditions. The main research question that this thesis intends to study is the ways in which future users of the deep underground workspace may benefit from adaptive and intelligent lighting in their day-to-day work activities. Whether the influence of a workspace equipped with adaptive and intelligent lighting and designed through a set of architectural lighting principles may promote well-being of employees and guests.

The first part of this thesis presents the theoretical background of the visual and non-visual effects of light and workspace architecture. The second part introduces the implementation of adaptive and intelligent technologies to architectural lighting design in the context of creating a new working environment in two underground spaces in Callio. Located on the main level, Retka restaurant will also operate as the new information centre. A few metres deeper, the Lab 2 will offer a new floor for research and business activities.

Through a series of scenarios, the design implementation of adaptive and intelligent lighting aims to respond to the visual and non-visual requirements of light of the future users of the deep underground workspace. The production of detailed descriptions for each scenario provides a robust conceptual framework for the lighting design. It aims to unfold the most adequate lighting behaviour that suits the underground working environment. The implementation plan for the lighting designs form a basis for future lighting pilots whereby the effects of lighting in underground environments will be studied.

Keywords

architectural lighting
adaptive and intelligent lighting
visual and non-visual effects
underground architecture
workspace design
activity based working
design for well-being

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[1] T. Ando. 'Church of Light, Tadao Ando: Complete Works', ed. Francesco Dal Co. London: Phaidon, 1995. p. 471.

" Light,
alone does not make light.
There must be darkness for light to become light -
resplendent with dignity and power.

Darkness,
which kindles the brilliance of light and reveals light's power,
is innately a part of light.

Yet,
the richness and depth of darkness has disappeared from our consciousness,
and the subtle nuances that light and darkness engender,
their spatial resonances -
these are almost forgotten.

Today,
when all is cast in homogeneous light,
I am committed to pursuing the interrelationship of light and darkness.

Light,
whose beauty within darkness is as of jewels that one might cup in one's hands;
light that,
hollowing out darkness and piercing our bodies,
blows life into "place". " [1]

ACKNOWLEDGEMENTS

Since my arrival in Finland as an architecture student, I became fascinated with the ever changing natural light conditions, ranging from the crepuscular nature of the light during the winter solstice to the never ending daylight during the mid summer solstice. I felt a strong attraction to learn more about our visual perception and non-visual effects of light.

The master's degree programme at the Oulu School of Architecture offers a unique opportunity to observe, learn and design with light in mind not only at an urban scale, but also at an interior space level. This is achieved through awe-inspiring lectures and hands-on workshops as well as by offering students the necessary resources to develop incredible future professionals be it in architecture or elsewhere.

I would like to express my gratitude wholeheartedly to my supervisor Dr Henrika Pihlajaniemi for her impeccable professionalism, undivided commitment to my learning development and trust in my capabilities to deliver the present body of work through moments of joy and hardship.

I consider myself far too fortunate to have shared the past six months surrounded by the teaching staff of Oulu School of Architecture. Thank you for all your encouragement.

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My most profound thanks to my close friends. No need to list here, you know who you are. I am truly blessed to count on you at every stage of my life.

In concluding, I would like to dedicate this work to my family for your caring gestures and loving words. Forever grateful for educating me to aspire to better myself with the hope to positively impact everyone around me.

INTRODUCTION

Background

By the end of 2019, ore extraction and refinement activities will have come to a halt in Pyhäsalmi Mine, northern Finland. There will remain a network of tunnels stretching to nearly one and a half kilometres in depth, together with fully functioning service infrastructure supplying above ground air, clean water, electricity, internet and waste disposal, to the deepest spaces underground.

The imminent closure of Pyhäsalmi Mine represents an extraordinary opportunity for business and research organisations whose operations may benefit from deep underground conditions. Callio has been established to manage the rehabilitation of Pyhäsalmi Mine into a world-class business and research underground facility.

The new user groups are envisioned to perform a number of activities that will require an upgrade to the current service infrastructure which includes lighting. The current lighting of Pyhäsalmi Mine may be sufficient for mining standards but it is highly questionable that the visual and non-visual lighting requirements of the potential users of Callio can be fulfilled under the existent lighting conditions. Upgrading the lighting infrastructure of this future deep underground facility is at the core of the rehabilitation programme.

This thesis studies the implementation of adaptive technologies to architectural lighting design solutions in order to meet the lighting requirements of potential users in two rooms of the future underground facility of Callio. The first space is a laboratory called 'Lab 2'. The second space is a canteen and visitor's information centre called 'Retka'.

Scope

The scope of this thesis is centred on the design implementation of adaptive and intelligent lighting solutions in response to the physiological and psychological needs of the potential users of an underground working environment with nil exposure to natural light. The more technical aspects of adaptive and intelligent lighting are outside the scope of this thesis.

The focus of this thesis is on the reuse of Pyhäsalmi Mine which serves as a backdrop for studying the effects of artificial light in such workspace. It provides a testing environment for a hypothesis respecting the lighting environment as affecting the physiological and psychological state of people.

As a result of the research by design task, the knowledge gained in the production of this thesis builds a solid foundation for the development of future lighting pilots that will study the visual and non-visual effects of light.

The general aim of this thesis is to study the lighting design solutions that are suitable for a workspace situated below ground with no exposure to natural daylight.

Research question

The inspirational question for this thesis was: "in which ways the future users of the deep underground facility of Callio may benefit from adaptive and intelligent lighting in their day-to-day work activities?". This prompted a further three research questions:

1. What are the lighting requirements of those working in underground workspaces? This question is addressed through literature review in chapter one.

2. Which aspects need to be considered when designing a workspace that should positively impact those working underground? A literature review with case studies was carried out in order to answer this question in chapter two.

3. How to design an adaptive and intelligent lighting environment through a set of architectural lighting principles that may promote well-being of employees and visitors of a workspace with nil exposure to natural light? The design part of this thesis studies the implementation of adaptive and intelligent lighting solutions to two spaces in Callio: Retka as canteen as well as visitor information centre and the Lab 2 as the laboratory, in chapter three and four.

Method

As a research-by-design thesis, the design implementation of adaptive and intelligent lighting to a workspace underground is explored as a method of inquiry. In the traditional lineal order, I began by researching, then defining the programme and finally designing. This thesis provides both written and non written forms of output as well as a clear and accessible discourse on the design process.

I relied upon a general literary review on architectural lighting so as to better understand the principles of lighting design in the built environment. In a similar way, I read extensively about adaptive and intelligent lighting in order to familiarise myself with the vocabulary, concepts and latest developments. I then narrowed my search to a selection of leisure and workspaces set underground that were studied from the point of view of lighting. The above-mentioned enabled me to observe how artificial lighting can influence our perception of the space. It provided me with the terms of reference for the design implementation plan in this thesis.

In the later design phase, I analysed the spatial and lighting characteristics of the site through written form and illustrations. I created a series of fictional stories about the future users utilising the space and assigned different adaptive and intelligent lighting solutions to those scenarios. It enabled me to build the overarching conceptual plan which is the backbone to the entire project. In closing, I put into practice all the knowledge that I acquire during the previous phases by implementing the ideas and concepts into the final design proposal.

Thesis structure

The main four chapters are 'Lighting below ground', 'Working below ground', 'Lighting at the end of the tunnel', and 'Final Project'.

In chapter one titled 'Lighting below ground', I focus on the principles behind the design of lighting and adaptive lighting environments while exploring the main themes of architectural lighting

In chapter two titled 'Working below ground', I intend to collect background knowledge by setting a classification of use of underground spaces and finally state a set of principles in designing working spaces underground.

In chapter three titled 'Lighting at the end of the tunnel', I present a historical analysis to the site as well as the spatial and lighting analysis for Retka and Lab 2. Then I introduce the eleven detailed scenarios and the conceptual themes that are behind the design of the adaptive and intelligent lighting environment for Retka and Lab 2.

In chapter four titled 'Final Project', I illustrate the result applying my previous research to the lighting design concept. The visualisations are intended to support the written material.

In closing, the final chapter titled 'Discussion' offers an overview to the results and other observations I encountered during the preparation of this thesis.

CHAPTER 1 LIGHTING BELOW GROUND

1.1 Principles in Architectural Lighting Design

1.2 Six Visual Principles of Light

1.3 Image-forming and Non-image-forming Effects of Light

1.4 Designing Adaptive and Intelligent Lighting Environments

1.1 Principles in Architectural Lighting Design

Lighting has technical, functional, spatial and an aesthetic properties. A good lighting installation must fulfil not only energy efficiency codes and safety standards, but also enable us to see without discomfort while creating an uplifting atmosphere. What follows is information on lighting design with an emphasis on its application to underground settings. In this very specific context, only artificial lighting is in use.

The relationship between architecture and lighting is that of mutual enhancement. To a great degree, daylight dictates form or materiality of our built environment, while artificial light complements the desired effects of daylight. As a result, designers are able to redefine the way in which we experience spaces.[2] A common misconception worth debunking is that architectural lighting only involves artificial lighting. Architectural lighting design pays reverence to natural lighting as much as to artificial lighting. As such, the evolution of architectural lighting is the concourse of new architectural forms and new technologies as illustrated on the right hand side table. The scope in this thesis is biased towards artificial lighting, due to the fact that the location of this project is entirely below grade. At such depths, there is no daylight to account for. It is the absence of daylight which lays out the design challenge. For there are no substitutes for the intrinsic characteristics of natural lighting.[3] Not even in terms of quantity, can artificial light deliver the illuminance of a clear sunny day.[4] But possibly the most important aspect to humans is the dynamic spectral changes of natural light on which our physical and psychological well-being depends upon.[5]

It is most likely that artificial lighting technology will advance in unimaginable ways. Yet, current technology seems to still focus on economic and performance factors of efficiency and visibility. Generally speaking, lighting designers are commissioned to deliver the former while creating atmospheres or moods that complement architecture and support functions in the space.[6] In order to reach this goal, it is important to incorporate technical recommendations

[2] H. Descottes, ‘Architectural Lighting: Designing with Light and Space’, Princeton Architectural Press New York, 2011. p. 80.

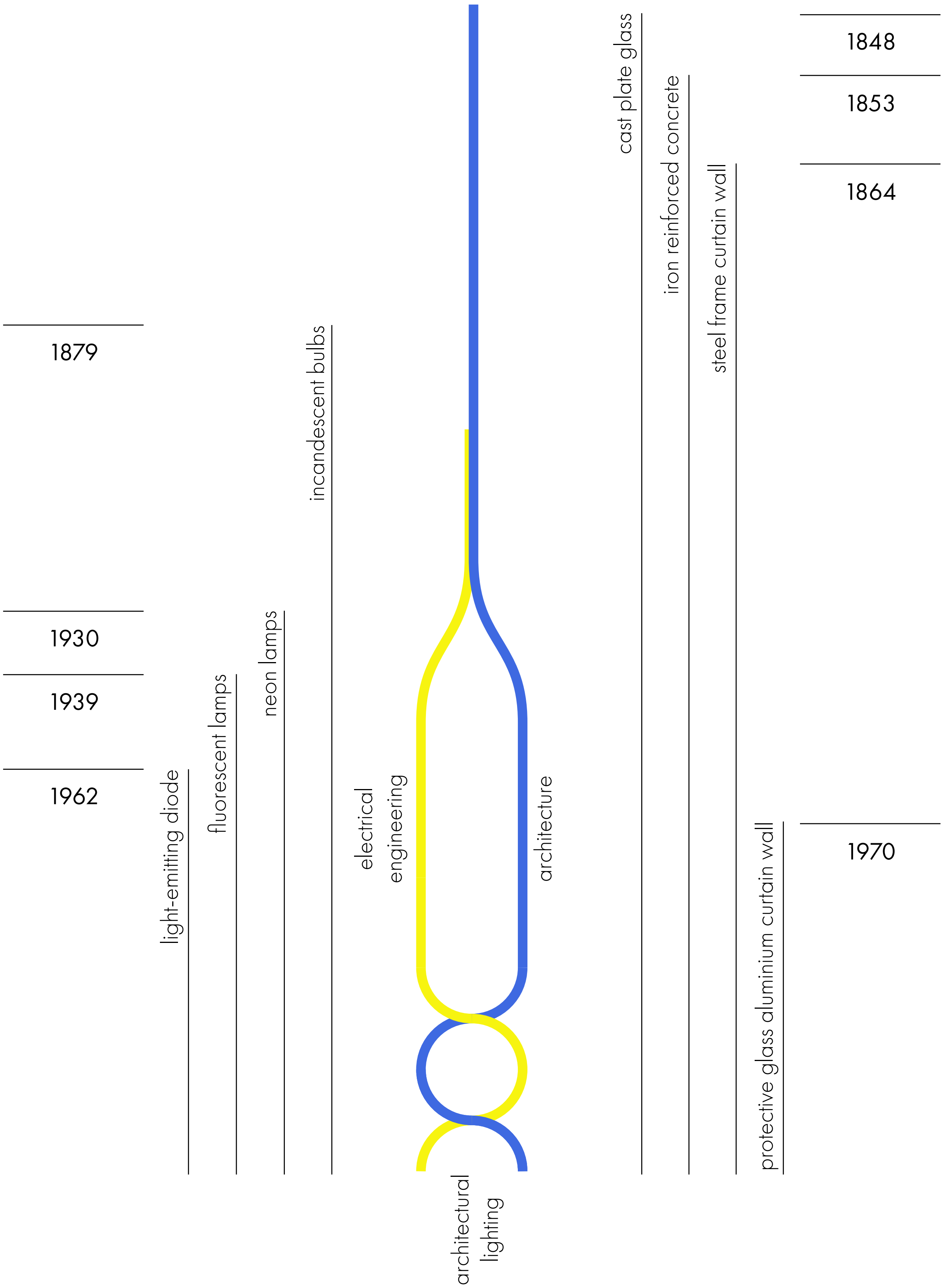
[3] U. Brandi and C. Geissmar-Brandi, ‘The practice of Lighting Design’, Birkhäuser, Basel, 2001. p. 23.

[4] The illuminance of a sunny day is 10,000 to 100,000 lux. Idem. p. 24.

[5] Idem. p. 24.

[6] W. M. Lam, ‘Perception and Lighting as Formgivers for Architecture’, edited by Christopher Hugh Ripman, McGraw-Hill, London, 1977.

Table 1. Innovations in Architectural Lighting



and design principles. Ironically, the mastery of design principles will yield good lighting while mere compliance to technical rules may result in indifferent or, at worst, bad lighting.[7]

From a technical standpoint, good lighting provides for correct objective measures of light intensity, light distribution, and spectrum, in anticipation of subjective sensations that the viewers may experience in the space. In qualitative terms, the perception of light intensity varies from dark to bright light. The connotations for darkness can range from fascination to unsafety whereas brightness signifies openness but can also create uncomfortable glare.[8] The perception of light distribution is diffuse and direct (or indirect) light which is associated with a cloudy sky or direct sunlight, respectively. Diffuse light communicates a soft atmosphere but direct sunlight transfers a rich contrast mood to an interior space.[9] We perceive spectrum as the colour temperature of light and hue. Warm or low colour temperatures show a close link to candlelight or fire while cooler or high colour temperatures are associated with the daylight colour palette. The meaning of coloured light is closely connected with local traditions[10] thus generalisations would not be accurate.

By way of illustrating the three basic physical characteristics of light, I resorted to building a basic 3D model of a imaginary office room with a table and two chairs and six recessed downlights in the ceiling. I explore the visual effects of light by comparing minimum and maximum values of light intensity and distribution. For the purpose of lighting analysis at this stage, I noted that light spectrum variability did not bring any perceptible changes. For consistency purposes, all simulations were staged in the same room whose size is three and a half by five metres in floor area by three metres in height, walls are rendered in matte white paint and flooring is polished concrete. LED recessed downlights with flush mounting tray from ERCO were chosen for this task. Specifically, ERCO's Quintessence round luminaire.

[7] P. Boyce, 'Editorial: Achieving Good Lighting', Lighting Research and Technology, 44:93, 2012. p. 1.

[8] T. Schielke, 'The Language of Lighting: Applying Semiotics in the Evaluation of Lighting Design', Leukos The Journal of the Illuminating Engineering Society, 2019.

[9] Idem.

[10] Idem.

○ 1	ERCO Quintessence round 221 mm in diameter
○ 2	ERCO Quintessence round 221 mm in diameter
○ 3	ERCO Quintessence round 221 mm in diameter
○ 4	ERCO Quintessence round 221 mm in diameter
○ 5	ERCO Quintessence round 221 mm in diameter
○ 6	ERCO Quintessence round 221 mm in diameter

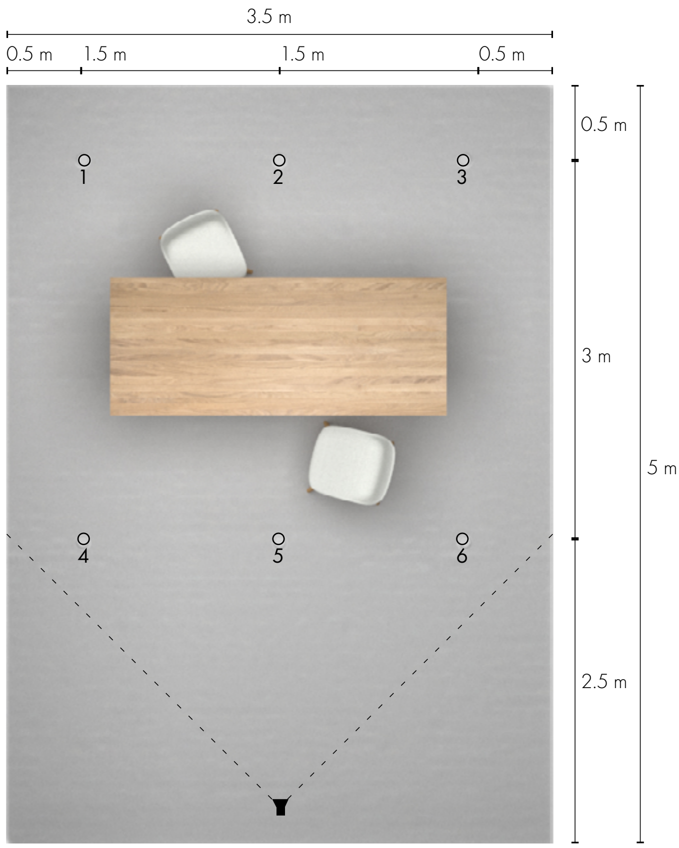


Fig. 1. Ceiling plan of room simulation

The elements of the scene are:
- Polished concrete for the floor
- Matte white painted concrete walls
- Mutto's Split table measuring 220 metres by 90 cm and 73 cm in height. Solid oak table top and solid cnc-milled wood pieced for the legs, all treated with harding oil.
- Norman Copenhagen Form Chair Oak White measuring 80 cm in height by 48 cm length and 52 cm wide. Shell is made of polypropylene plastic material and the legs are made of oak timber.

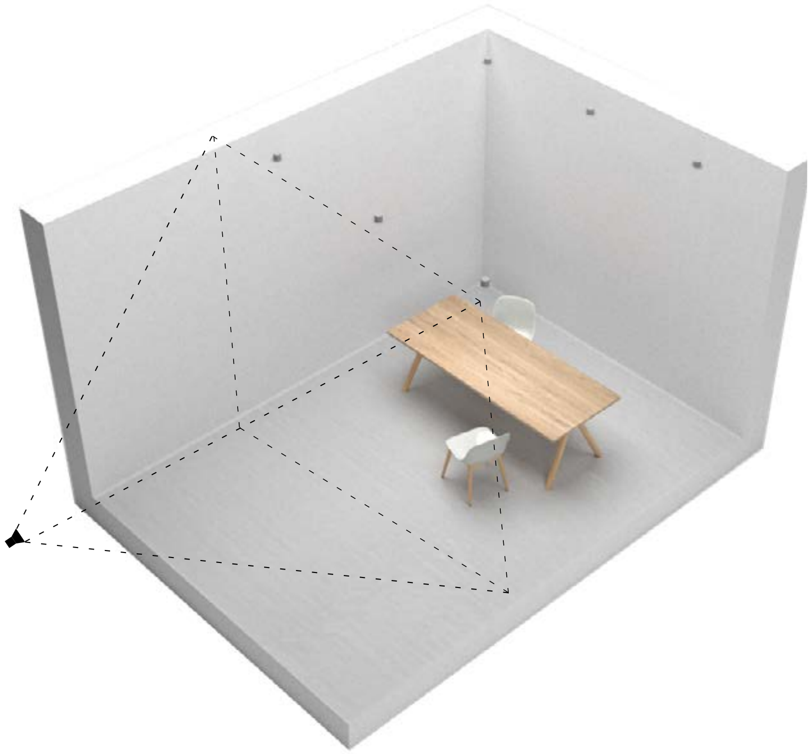


Fig. 2. Isometric view of room simulation

The four visualisations on the right hand side demonstrate how changes in light intensity and distribution can change our perception of the space.

Given no changes in the characteristics of the room, the presence of a wide flood light like in scene one and two illuminate the floor surface evenly. In scene one and two, the luminaires emit light to an area of 35º around the line of light while the fallout area is over 60º. It can be clearly seen in figure six that the light emitted is almost a perfect cone in shape. These diffuse flood lights are very near each other as seen on the back wall and by the time they reach floor height, they are completely overlapping.

The narrow angled light beam in scenes three and four is just below 7º and the fallout area is 10º. It results in two areas of high contrast: the narrow bright area where the spot of light falls on and all other remaining areas which are not directly illuminated and concealed. In scene three, light intensity of the luminaires is quite low so the desk and chair are almost invisible, while in scene four the same objects receive indirect light from very bright spotlights.

Not only can light distribution reveal or hide objects, but also the position of the luminaires can affect our field of vision. However, running in parallel to the units of lumens, degrees and kelvins is the equally important integration of light in the built environment.

Fig. 3. Scene 1: Wide beam and dim downlighting

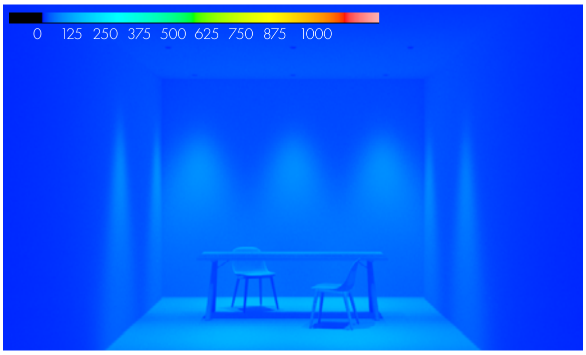


Fig. 4. Light intensity analysis for scene 1

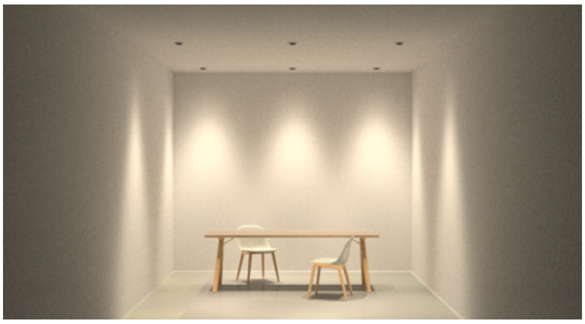


Fig. 5. Scene 2: Wide beam and bright downlighting

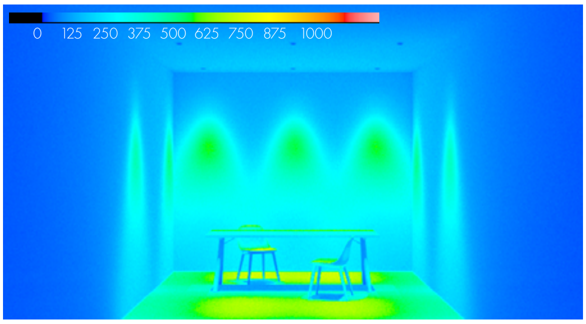


Fig. 6. Light intensity analysis for scene 2

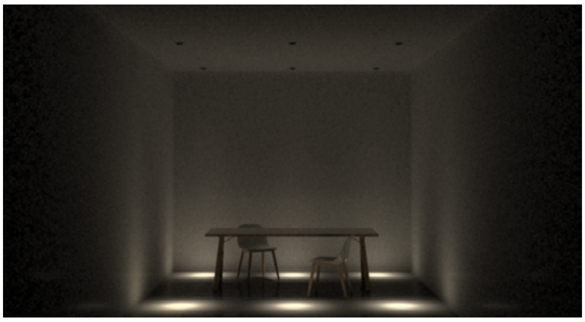


Fig. 7. Scene 3: Narrow beam and dim downlighting

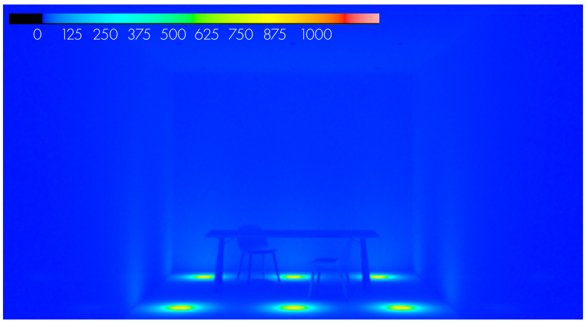


Fig. 8. Light intensity analysis for scene 3

Fig. 9. Scene 4: Narrow beam and bright downlighting

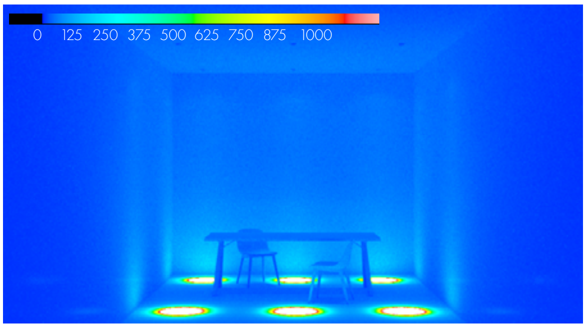


Fig. 10. Light intensity analysis for scene 4

1.2 Six Visual Principles of Light

Architects have always aspired to create novel sensations and forms of light inside buildings which lead to the many inventions of architecture structure in history, such as the hemispherical dome with open oculus of the Pantheon built in Ancient Roman times that creates a heavenly light effect or the ribbed vaulting system allowing for larger clerestory windows of stained glass for a startling effect of coloured light in the Gothic period. While the burning flame in a candle or an oil or gas lamp had been the only artificial source of directed and distributed light for thousands of years, the apotheosis of the electric bulb at the turn of the nineteenth century[12] redefined the way in which we utilise a given space independently from the presence or absence of daylight or time of day. Our sense of safety and comfort is determined by the control of light intensity that reveals or negates the visual and spatial continuity.

Materiality together with form and colour is correlated to the concept of luminance. The degree of light absorption of a given surface material dictates how light waves will be reflected back to our eyes. For a material might seem bright if it is of high reflectance, or dark if it is of low reflectance. This is a powerful tool in lighting design that a highly reflective material can become a secondary light source.[13] Glare may occur if light falls on a highly reflective material and is misdirected to the eye. However, our tolerance to brightness depends on mood, ambience, necessity and context.[14] So, on another occasion, controlled glare might create a bundle of bright light that enhances a space positively, which is called sparkle. Another important visual effect linked to illuminance is contrast. Contrast is expressed as the ratio between light and darkness and it helps us perceive visual hierarchy of elements in space or simply distinguish background and foreground or architectural form and space. Interior spaces will typically score ratios of 10:9 or 5:4 for a desired uniformity of luminance or low contrast.[15] High contrast ratios of 10:1and above are considered dramatic and likely not recommended for workspaces where medium to low luminance are found more suitable for comfort, among other practical reasons.[16]

[12] W. Schivelbusch, 'Disenchanted night: the industrialisation of light in the nineteenth century', University of California Press, Berkeley, 1988. p. 58.

[13] H. Descottes, 'Architectural Lighting: Designing with Light and Space', Princeton Architectural Press New York, 2011. p. 35.

[14] Idem. p. 38.

[15] Idem. p. 38.

[16] Idem. p. 38.

Table 2. Light intensity and luminance

light intensity		luminance		
static control	dynamic control	reflectance	contrast	sparkle
150 lx dimmer	dim down	10% weak absorption	10:9 uniform	glare
250 lx dim	brighten up	30% light absorption	5:4 subtle	glitter
500 lx bright	light shower	50% mild absorption	10:1 dramatic	sparkle
750 lx brighter	dim pulse	80% great absorption	20:1 extremely dramatic	
1000 lx brightest				

Electromagnetic spectrum of light cannot be experienced in its entirety by the human eye. Humans only perceive visible light as a range of wavelengths that fall between ultraviolet and infrared radiation.[17] There are the seven visible colours in the electromagnetic spectrum of light: red, orange, yellow, green, blue, indigo, and violet.

The table on the right hand side illustrates colour and temperature properties of light.

Hue and saturation of a certain material can be altered by the incident light. As an example, a material seen as red may change its colour aspect to greenish if the hue of the incident light is green. We perceive black as the absence of light waves while white light is the addition of all visible colours in the electromagnetic spectrum of light.

The colour temperature of white light can range from too warm (1,500K - 2,000K) to warm (2,500K - 3,000K) to neutral (3,000K - 4,000K) to cool (4,000K to 6,500K) or very cool (6,500K and higher).[18] We have internalised the changeable visual appearance of white light of daylight as the sun travels an arc of 180 degrees through the sky in such a way that we can guess the time of day and month of year just by observing the atmospheric light. The variation of colour, hue and saturation in light for an interior space can be an effective way to give a sense of atmospheric movement and the passing of time.[19]

[17] H. Descottes, 'Architectural Lighting: Designing with Light and Space', Princeton Architectural Press New York, 2011. p. 42.

[18] Idem. p. 42

[19] Idem. p. 51

Table 3. Colour and temperature

saturation and hue		colour temperature	
red-green-blue light absorption	red-green-blue light mix	tunable white luminaires	
white light absorption	N white light	3000 k warm	warm to neutral
green light absorption	G Y C R M B tinted light	4000 k neutral	neutral to warm
blue light absorption		6500 k cool	cool to warm
red light absorption			warm to cool
			cool to neutral
			neutral to cool

Possibly the most powerful tool in revealing and defining space in architectural lighting is the pairing of distribution and directionality of light.[20] Through the direction of light, the eye will perceive flatness and depth, foreground and background, object and architecture, and ultimately creating the visual structure of a composition in space.[21] Through the distribution of light, the eye perceive high contrast or low contrast, hard or soft shadows, that ultimately heightens the visual reading of a material or surface.[22]

There are two types of light distribution: diffuse and direct. A luminaire that provides diffuse lighting produces uniform illumination with reduced shadows or reflections. A point light source provides direct lighting which produces shadows and reflections.

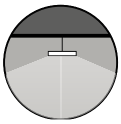
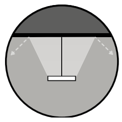
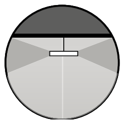
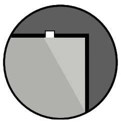
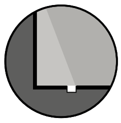
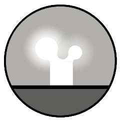
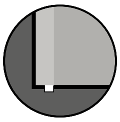
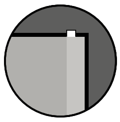
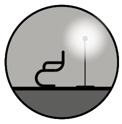
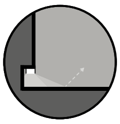
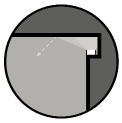
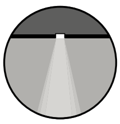
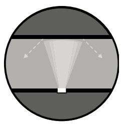
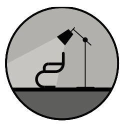
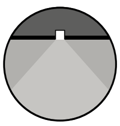
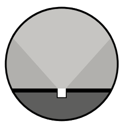
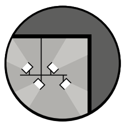
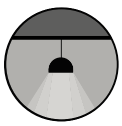
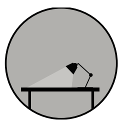
There are three types of light direction: up, down or all directions. The position of the light source determines the direction of the light being emitted.

[20] H. Descottes, 'Architectural Lighting: Designing with Light and Space', Princeton Architectural Press New York, 2011. p. 73.

[21] Idem. p. 73

[22] Idem. p. 72

Table 4. Distribution and directionality

	down	up	else
diffuse	 suspended-down	 suspended-up	 suspended-bi
	 wallwash-down	 wallwash-up	 luminous object
	 wall-grazing-down	 wall-grazing-up	 local
	 cove-down	 cove-up	
direct	 narrow-down	 narrow-up	 personal
	 wide-down	 wide-up	 multiple
	 pendant		 intimate

The height where a light source is placed can also influence our perception of the space and time. It is our observation of the movement of the sun and the shadows on the surface of the Earth that serve us as a visual datum.[23] A type of biomimetric approach in indoors environments could consist of cove lighting at the top of the wall during the day to draw the visitor's eyes to the upper limits of the room and reveal the full extent of the space, whereas at night-time cove lighting at the base of the wall can confine the visual extent of the space to the lower section of the room providing for comfort and a sense of intimacy.

Density is defined by the number of light sources in a given area and the organisational character of grouping such light sources.[24] Despite the fact that there exists certain standards of density for particular spaces and programmes, it is ultimately the visual understanding of the effects of density that may be altered in accordance to an specific narrative, space, programme or emotion.[25] In general terms, the eye will be drawn to differing densities of light that convey lesser or greater importance in the space. The grouping patterns can reveal a certain rhythm realised through the implementation of repeating forms and spatial schemes that play in tandem with surrounding architectural forms, which ultimately affect our perception of time and depth.[26] Changes in density have the capacity to either slow down the pace or re-energise the atmosphere of a space, adding layers of symbolic meaning and fostering interpretations of the architecture.

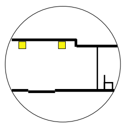
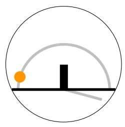
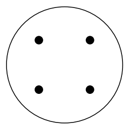
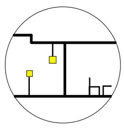
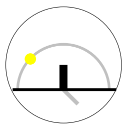
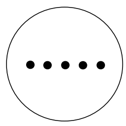
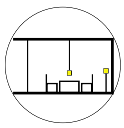
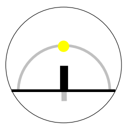
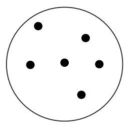
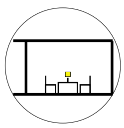
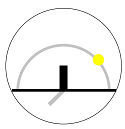
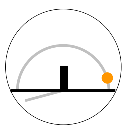
[23] H. Descottes, 'Architectural Lighting: Designing with Light and Space', Princeton Architectural Press New York, 2011. p. 53.

[24] Idem. p. 62

[25] Idem. p. 72

[26] Idem. p. 69

Table 5. Height and density

height		density
intimacy	time	rhythm
 public (general)	 sunrise	 grid
 public (local)	 morning	 lineal
 personal	 noon	 random
 intimate	 afternoon	
	 sunset	

1.3 Image-forming and Non-image-forming Effects of Light

In addition to how we may associate or perceive light, it has been shown that the effect of light encompasses important outcomes such as alertness, mood, cognitive performance, social behaviour, and mental health and well-being. Researchers cluster the effects of light information received and processed by the eyes into two basic categories: that of visual, image-forming, pathway and that of non-visual, non-image-forming, pathway.[27]

Image-forming pathway concerns the processing of light information via the visual system. This pathway explains how different light conditions influence task visibility, visual performance and comfort, and the visual impressions of spaces and the persons and objects in that space.[28] Visual performance is generally defined as the speed and accuracy of performing a visual task. The definition of visual comfort is still under debate because the mechanisms behind ocular discomfort are not yet fully understood.[29] Visual experience refers to how light may shape our mindset and behaviour as we perceive, assess and react to spaces, objects and tasks.

Non-image-forming pathway effects are commonly categorised as circadian or acute. This second pathway has received a lot of attention since the discovery of a fifth type of photosensitive receptors in the human eye.[30] So much so that it has paved the way for a better understanding of the photo-biological effects of light intensity, spectrum, duration and timing on humans. This type of photosensitive receptors have proven to be directly linked to our central circadian pacemaker, located in the hypothalamus, and alertness and sleep-related regions in the central parts of our brain, while other photosensitive receptors in our eye target the visual cortex.[31] For more acute responses that emerge and dissipate upon or after light exposure, one can observe an instant change at a physiological, endocrinological or brain activity level. For example, a bright or blue-enriched light with a wavelength between 470-480nm affects the release or suppression of hormones melatonin and cortisol.[32]

[27] Y. A. W. de Kort, 'Tutorial: Theoretical Considerations When Planning Research on Human Factors in Lighting', Leukos The Journal of the Illuminating Engineering Society, 2019.

[28] P. R. Boyce, 'Human Factors in Lighting', CRC Press, London, 2014.

[29] Idem.

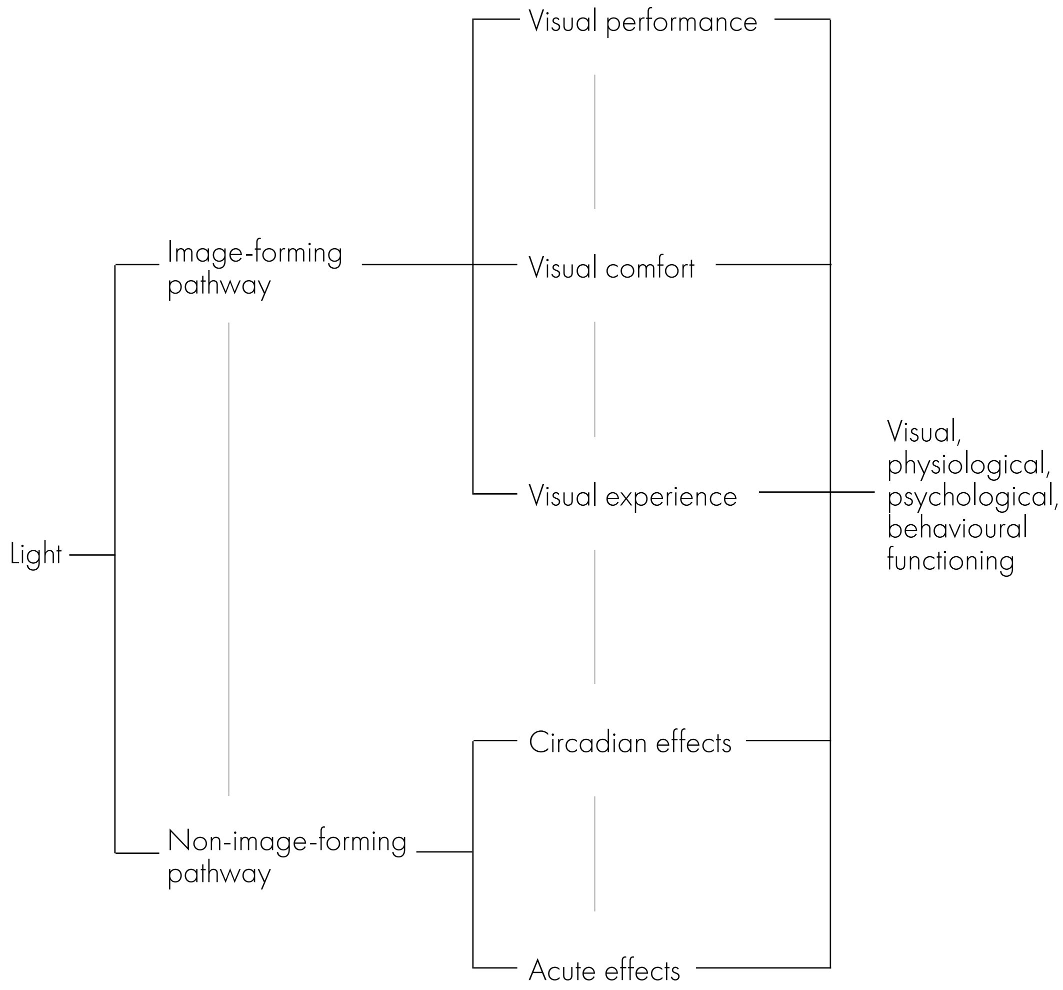
[30] D. M. Berson, F. A. Dunn, M. Takao, 'Phototransduction by retinal ganglion cells that set the circadian clock', Science, 295:1070-3, 2002.

[31] G. Vandewalle, P. Marquet, D. J. Dijk, 'Light as a modulator of cognitive brain function', Trends Cognitive Science, 13(10):429-38, 2009.

[32] D. J. Dijk and S. N. Archer, 'Circadian and homeostatic regulation of human sleep and cognitive performance and its modulation', PERIOD3, Sleep Medicine Clinics, 4, 111–125, 2009.

[33] Adapted from Y. A. W. de Kort and J. A. Veitch, 'From blind spot into the spotlight', Journal of Environmental Psychology, 39:1-4, 2014.

Table 6. Image-forming and non-image-forming pathways [33]



Through image-forming and non-image forming mechanisms, light exerts a powerful influence on the visual, physiological, psychological and behavioural human functioning. The overlap in effects of image-forming and non-image-forming mechanisms is clearly reflected in the lighting designs. In this thesis, the emphasis has been placed on the well-being of workers. We understand lighting for well-being as creating a lighting environment that responds positively to both physiological and visual (as in *seen well*) needs of its users.

1.4 Designing Adaptive and Intelligent Lighting Environments

In contrast with the traditional lighting technologies, adaptive lighting environments are characterised by the use of interactive technologies. The design of adaptive lighting environments entails interaction design challenges.[37] These technologies have built-in computational power that collect information from its environment and its users or from any other information relevant to the intended lighting behaviour.[38] In an adaptive lighting environment, this intended lighting behaviour can follow diverse models, such as a type of biodynamic lighting environment that features variable changes of light intensity and spectrum, in the same way natural daylight behaves.[39] In closing the process cycle, the new lighting environment may alter user behaviour which in turn will trigger further lighting system adaptation.[40]

As a fairly new area of design and research, the terminology associated to adaptive lighting has not been globally standarised to date.[41] In her doctoral thesis, Henrika Pihlajaniemi defines the concepts of the terminology with different degrees of user and system interaction present in lighting environments. The table on the right hand side compares the least responsive type of interaction to a system that is highly interactive and able to take the role of partner.[42]

Dynamic lighting environments are preset and offer no adaptation to environment or users, in the way that adaptive lighting offers. In implicit interaction, the system autonomously interprets user action as input data, e.g. occupancy sensors detect people, then lights turn on. For explicit interaction to occur, the system utilises feedback mechanisms from user inputs, such as a command line or a gesture or speech.[43]

37 R. Magielse, 'Designing for adaptive lighting environments : embracing complexity in designing for systems', Technische Universiteit Eindhoven, Eindhoven, DOI: 10.6100/IR771846, 2014. p. 26.

38 H. Pihlajaniemi, 'Designing and experiencing adaptive lighting. Case studies with adaptation, interaction and participation', University of Oulu Graduate School; University of Oulu, Oulu School of Architecture Acta University of Oulu H 3, Oulu, 2016. p. 15.

39 Idem. p. 16.

40 Idem. p. 16.

41 Idem. p. 15.

42 Idem. p. 16; G. Schmitt, 'Information Architecture: Basics of CAAD and its future: Architecture and Informatics', Birkhäuser, Basel, 1999.

43 A. Schmidt, 'Implicit Human Computer Interaction Through Context', Springer-Verlag, London, DOI: https://doi.org/10.1007/BF01324126, 1990. p. 192.

44 H. Pihlajaniemi, 'Designing and experiencing adaptive lighting. Case studies with adaptation, interaction and participation', University of Oulu Graduate School; University of Oulu, Oulu School of Architecture Acta University of Oulu H 3, Oulu, 2016. p. 17-18.

45 I. Chew et al, 'Smart lighting: The way forward? Reviewing the past to shape the future', Energy and Buildings 149, 2017. p. 181.

46 H. Pihlajaniemi, 'Designing and experiencing adaptive lighting. Case studies with adaptation, interaction and participation', University of Oulu Graduate School; University of Oulu, Oulu School of Architecture Acta University of Oulu H 3, Oulu, 2016. Fig. 17.

47 Idem. p. 45.

48 Idem. p. 29.

Table 7. Implicit versus explicit lighting interaction

implicit interaction	explicit interaction
user's actions as input data	feedback mechanisms from user inputs
adaptive and intelligent	interactive and participatory
Adaptive lighting is gaining momentum since it has been proven to have positive impact on energy efficiency, human well-being or simply as an advancement in technology.[44] But the networked device interconnectivity in the built environment is also fuelling the demand of intelligent or smart lighting[45] with real-time adaptation capabilities.[46]	Interactive lighting requires the user to intentionally control lighting.[47] Participatory lighting is a form of interactive lighting that requires the creative input or any other type of meaningful involvement from participants.[48]

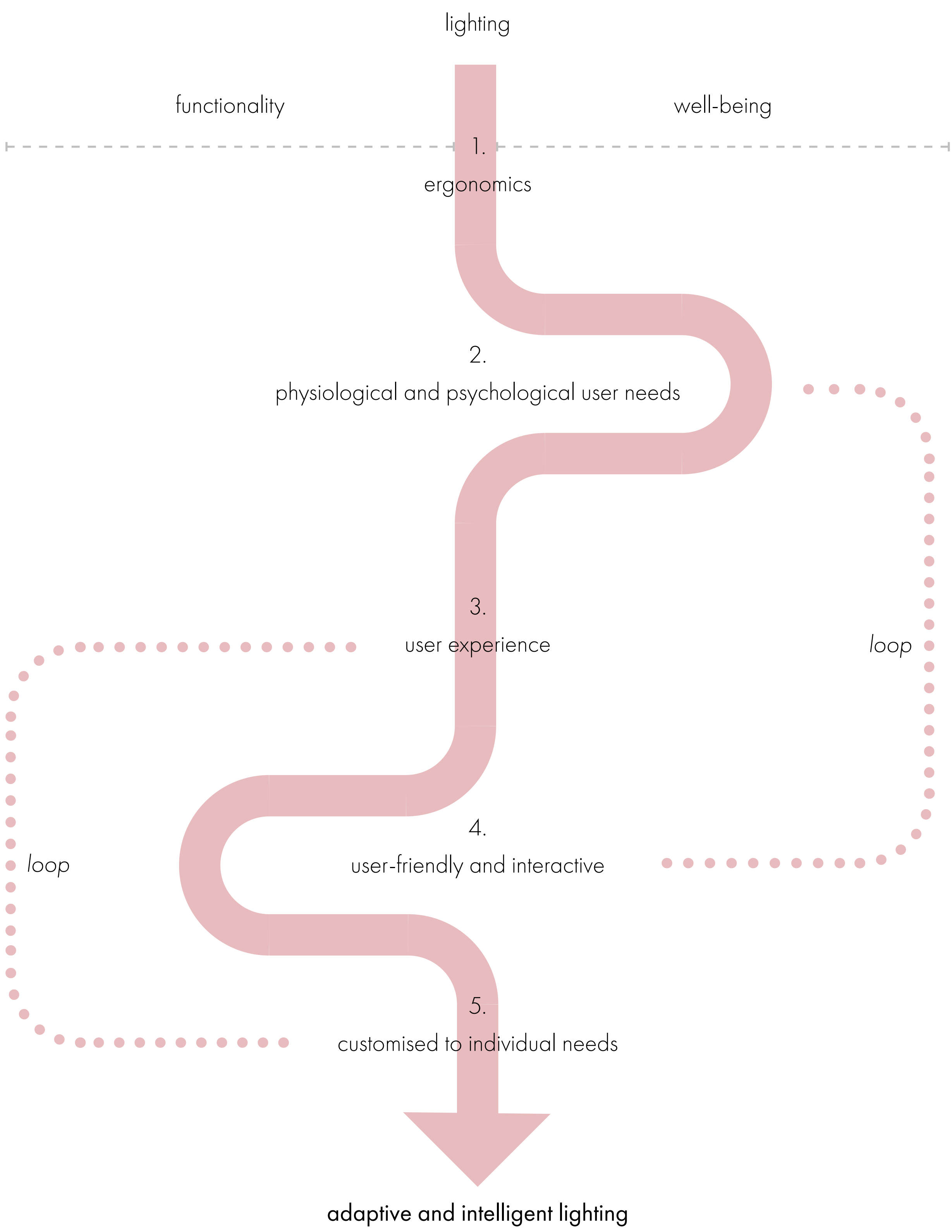
The role that the designer plays is quite significant in delivering adaptive lighting environments since it must meet functionality, user satisfaction, aesthetic qualities and even artistic expression. In order to do so, the lighting environment must behave in accordance to a set reference information, knowledge or logic that the designer created from the outset.[49] With the help from the new digital controllers attached to LED sources, designers have moved beyond the basic dimming technology of yesteryear. These fixtures offer various dynamic control options which can be dynamically turned on or off depending on the input source. An input can be an external source to the environment where the system is installed, such as statistical data, or an internal source, such as local sensors or individual local controls.[50] Ultimately, the lighting design strategy springs out from the amount and type of inputs the designer may require the system to respond to. In turn, the definition of the set of controls generally includes a sequence of operation that dictates how the lighting system shall operate. Detailed lighting control sequences are necessary for the effective operation of the lighting system.

In this thesis, the approach to designing an adaptive lighting environment for Callio is not technological or device oriented but it rather gears towards the user's experience. How light is experienced by humans is of completely subjective character. In the specific underground context of Callio, the users ought to be representative of possible lighting preferences in terms of perceived safety (physical comfort) and functional comfort. An operative distinction can made between the two aspects right away. It is an standard requirement that safety must be guaranteed. It is an additional quality that comfort is satisfactory. A great emphasis has been placed in the understanding of such aspects and its related determinants because it constitutes the entire rationale of the design. In order words, the specific knowledge has been modelled to explore light's visual effect over user perception of underground spaces with a focus on perceived safety and functional comfort.

49 H. Pihlajaniemi, 'Designing and experiencing adaptive lighting. Case studies with adaptation, interaction and participation', University of Oulu Graduate School; University of Oulu, Oulu School of Architecture Acta University of Oulu H 3, Oulu, 2016. p. 32.

50 International Commission on Illumination, 'Research Strategy: Adaptive, Intelligent and Dynamic Lighting', 2018. Accessed on 14-March-2019. files.cie.co.at/872_CIE%20Research%20Strategy%20%28August%202016%29%20-%20Topic%205.pdf

Table 8. Design process of adaptive and intelligent lighting



[51] J. Tanizaki. 'In Praise of Shadows', trans. Thomas J Harper and Edward G Seidensticker. Sedgwick: Leete's Island Books, 1977. p. 30

" There is an old song that says

"the brushwood we gather—

stack it together, it makes a hut;

pull it apart, a field once more."

Such is our way of thinking—

we find beauty not in the thing itself,

but in the patterns of shadows,

the light and the darkness,

that one thing against another creates. " [51]

CHAPTER 2 WORKING BELOW GROUND

2.1 Perception, Cognition and Emotion

2.2 Underground Space Typologies by Function

2.3 Underground Knowledge Production Workspaces

2.4 Activity-based Working

2.1 Perception, Cognition and Emotion

Contact with light and air is so important that there are regulations concerning these aspects. With a dash of ingenuity, underground projects can both comply with such requirements and diminish any feeling of fear or other prejudices. In this respect, designers aspire to narrow the gap between the sunlight and airy above ground and its counterpart below. This chapter contains relevant information about perception, function and form of subterranean spaces.

The three basic conditions for laying out an underground space is light, sight and view, for a sense of safety and identity. Yet, oftentimes, the atypical environment of subterranean spaces may be developed with a great degree of engineering of various elements, such as light, air, sound, colour, form or even scents, with little or no regard to cohesive design.

Human beings receive stimulation from the environment which triggers certain mental processes, and ultimately determine our behaviour. It is the field of experimental psychology that studies the general human functions of perception, cognition, emotion and motivation.[52] The challenge for any underground development is to identify the mental processes that shape our perception and to recognise the extent to which users experience positive or negative emotions in the space.

The first and perhaps the most obvious feature shared among all underground buildings is that the shape of the building is invisible. This is due to the fact that two of the most prominent architectural elements, exterior façades and windows, are lacking. If people are unable to have an overall image of the building, then finding one's way around the building may become quite a difficult task, which can easily cause anxiety.[53] As more disorganised the pattern of circulation becomes, the greater the insecurity and fear. However, one should disassociate the term 'underground' with any negative aspects relating to security and safety. The hidden character of any underground space offers a high degree of privacy and protection.[54]

[52] S. Durmisevic, 'Perception Aspects in Underground Spaces using Intelligent Knowledge Modelling', Delft University Press, Delft, 2002. p. 22.

[53] E. H. Lee et al, 'A Psychological Approach to Understanding Underground Spaces', Environmental Psychology, Frontiers in Psychology, 2017. p. 4.

[54] Idem. p. 4.

In this sense, the feeling of protection from a safety or security point of view differ on whether the risk or danger may originate from the physical environment or from a specific human behaviour.[55] Safety risks can be dealt with if checks are run on a regular basis, whereas security risks can be prevented with increased surveillance and better visibility of the built environment.[56]

Another trait of an underground building is the lack of a view which may provoke a feeling of being closed in or isolated.[57] The limited visual stimuli, of a windowless space can elicit fear of emergency situations or poor air quality even when the mechanical ventilation is optimal. Accentuating entrance and exit signposts and transition to other spaces or the addition of more exit routes connecting to the ground level can offer a helpful relief.[58] The latter architectural intervention could consist of increasing the number of escalators or lifts in order to offer more ways to connect to the aboveground. Such passageway is a key element in the reduction of the awareness of separation and should promote a sense of familiary to the users.[59]An interesting solution could arise from the combination of vertical shafts and light tunnels that may provide a more direct visual connection to the world above. Moreover, spatial variety can break the monotony of being underground by creating a sequence of spaces that are vast, then intimate, then large again. Changes in light contrast is a technique to increase identity and significance in the space: bright versus dim lighting, open versus closed, high versus low ceilings, polished versus rough walls, vegetation versus stone.

The third characteristic is simply the fact of being underground, which for the least optimistic person means a cold, dark and damp place[60] in comparison to the above ground level which is perceived as more open, public and of urban use.[61] Oftentimes subsurface environments have more built structures and little or no natural features which can easily arise a feeling of foreignness, possibly due to our human preference to the natural over the built form.

55 E. H. Lee et al, 'A Psychological Approach to Understanding Underground Spaces', Environmental Psychology, Frontiers in Psychology, 2017. p. 4.

56 O. Newman, 'Defensible Space: Crime Prevention through Urban Design', Macmillan, New York, 1972.

57 E. H. Lee et al, 'A Psychological Approach to Understanding Underground Spaces', Environmental Psychology, Frontiers in Psychology, 2017. p. 2.

58 J. Carmody and R. Sterling. 'Underground Space Design. A Guide to Subsurface Utilisation and Design for People in Underground Spaces', Van Nostrand Reinhold, 1993. p. 47.

59 E. H. Lee et al, 'A Psychological Approach to Understanding Underground Spaces', Environmental Psychology, Frontiers in Psychology, 2017. p. 3.

60 E. von Meijenfeldt et al., 'Below Ground Level. Creating New Spaces for Contemporary Architecture', Birkhäuser, Basel, 2003.

61 M. Labbé, 'Architecture of underground spaces: from isolated innovations to connected urbanism', Tunnelling and Underground Technology, 55. p. 160.

As first popularised by Edward O. Wilson in the eighties, the concept of biophilia describes the innate relationship between humans and nature and the physical and psychological importance for humans to stay close to nature.[62] Environmental psychology research proves that our direct connection to nature promotes psychological restoration.[63] The loss of contact with nature may be mitigated if greenery is incorporated into the design of underground environments.

An example of positive associations to underground spaces, such as protection, romanticism, peace and quiet is the cavernous, labyrinthine thermal baths at Vals, in which architect Peter Zumthor developed an architecture concerned with contiguity and enclosure, weightlessness and heaviness, beautiful materiality, sound and illumination for an intense and sensory rich experience.[64] Light and its combinations are the main elements that create environments for the visitors to experience the benefits of water. Luminaires are housed inside the narrow slits that cut the entire slab in long horizontal lines connecting rooms and thus accentuating the peaceful horizon of the water. Zumthor's architecture reflects all the positive associations there can be for subterranean spaces. In other words, Zumthor creates a heavenly subterranean bathhouse out of a burrow which creates a type of cognitive dissonance between negative expectations and favourable experience after visiting. Designers who are able to identify the psychological responses which are at the base of perceptions, can influence the users' feelings of arousal or alertness.[65] For instance, one can compensate high levels of arousal with arousal reducing effects or increase alertness with arousing environments.

[62] E. O. Wilson, 'Biophilia: The human bond with other species', Harvard University Press, Cambridge, 1984.

[63] A. E. van den Berg, T. Hartig, and H. Staats, 'Preference for nature in urbanised societies: Stress, restoration, and the pursuit of sustainability', Journal of Social Issues, 63(1), 2007. p. 79-96.

[64] R Ryan, 'Thermal Baths in Vals, Switzerland by Peter Zumthor', The Architectural Review, 1 August 2015. Accessed online on 16 February 2019. https://www.architectural-review.com/buildings/thermal-baths-in-vals-switzerland-by-peter-zumthor/8616979.article

[65] E. von Meijenfeldt et al., 'Below Ground Level. Creating New Spaces for Contemporary Architecture', Birkhäuser, Basel, 2003.

2.2 Underground Space Typologies by Function

At present, the most typical underground development is a transitory-type space, such as shopping centres and underground train stations.[66] The reason being is that people feel usually averse to staying underground for long periods of time. Therefore, setting up a design framework for developing a better underground space involves taking into account not only the nature of the activity enacted and the length of time expected to be spent there, but also the challenges and advantages of such environments on the psychological and physiological well-being of its users.

An underground space is understood as an enclosed environment below the surface of the earth,[67] which can host a diversity of functions. The table on the right hand side lists two categories of use of underground spaces: either people-oriented or product-oriented uses.

Generally speaking, when designing an underground space where people are expected to spend a considerable amount of time, health and well-being of its users are critical factors to be taken in account. However, it is generally less important to consider such factors when the underground space is of product-oriented use, even though staff would greatly benefit from a more human-centered aproach.[68]

The original use of the underground space in this project is product-oriented: a mine. The aim of the proposed adaptive lighting environment is a first step into the rehabilitation of the existent mine as a living laboratory and business hub. The new activities at Callio can be associated to those of people and product-oriented use: recreational, commercial, storage, agriculture, knowledge production, utilities and energy storage. Yet, Callio has to comply with requirements similar to those of working environments elsewhere, which are related to indoor climate, light, safety, health and working hours.[69] On a positive note, employees who have experience underground are more likely to express approval about working underground again in the future.[70]

[66] J. Carmody and R. Sterling. 'Underground Space Design. A Guide to Subsurface Utilisation and Design for People in Underground Spaces', Van Nostrand Reinhold, 1993. p. 47.

[67] Idem. p. 47.

[68] Idem. p. 47.

[69] E. von Meijenfeldt et al., 'Below Ground Level. Creating New Spaces for Contemporary Architecture', Birkhäuser, Basel, 2003.

[70] E. H. Lee et al, 'A Psychological Approach to Understanding Underground Spaces', Environmental Psychology, Frontiers in Psychology, 2017. p. 3.

[71] Adapted from J. Carmody and R. Sterling, 'Underground Space Design. A Guide to Subsurface Utilisation and Design for People in Underground Spaces', Van Nostrand Reinhold, 1993. p. 47.

Table 9. Underground space use by function [71]

major functions	people-oriented uses	product-oriented uses
residential	single-family	
	multifamily	
non-residential	religious	industrial
	recreational	parking
	institutional	storage
	commercial	agriculture
	knowledge production	
infrastructure	transportation of passengers	transportation of good
		utilities
		energy
		disposal
		mines
military	civil defense	military facilities

2.3 Underground Knowledge Production Workspaces

Work environmental research measures the user-environment relation through employees' satisfaction and feelings towards their work environment as expressed in sense of territory, ownership and belonging, and employee productivity.[72] The perception of the workspace environment and performance at work have been proven to be closely related.[73] Ambient conditions, furniture layout and ergonomics, and process issues[74] are generally accepted to influence work satisfaction. Work satisfaction affects employee's performance of work-related tasks, which generally refers to as functional comfort.[75] It has been found that environmental design influences work productivity in three different scales: individual, group and organisational. The speed and accuracy of an individual task performance can be affected by environmental conditions such as visual conditions and furniture ergonomics[76] among others. The environmental determinants of group work effectiveness include the location of work areas and shared spaces and access to shared tools and equipment.[77] As a macro-environment, the organisation's entire workspace can be affected by accessibility, centralisation, adequate building amenities and attractive break areas among others.[78]

In order to debunk the negative public perception of underground workspaces as confined, it is essential that there is clear spatial layout, visibility, spatial differentiation in size and surface colours or the use of signs can provide for a good sense of orientation[79] and prevent haphazard flow of people. This adaptation of the physical workspace environment to support the demands of its users with ever changing task requirements helps optimise user comfort and work productivity.[80]

[72] J. Vischer, 'The concept of workplace performance and its value to managers', California Management Review, 49:2, 2006. p. 98.

[73] J. Vischer, 'Towards an Environmental Psychology of Workspace: How People are Affected by Environments for Work', Architectural Science Review, 51:2, 2008. p. 97. DOI: 10.3763/asre.2008.5114

[74] Idem. p. 98.
Ambient: lighting, air quality and thermal comfort
Furniture layout and ergonomics: workstations and shared amenities
Process issues: user participation in design, meeting business and organisational objectives

[75] Idem. p. 99.

[76] Idem. p. 102.

[77] J. Heerwagen et al., 'Collaborative knowledge work environments', Building Research and Information, 32:6, 2004. p. 510-528.. p. 102.

[78] J. Vischer, 'The concept of workplace performance and its value to managers', California Management Review, 49:2, 2006. p. 62-79.

[79] W. Muller, 'Order and meaning in design', Delft University of Technology Series, Lemma Publishers, Utrecht, 2001. p. 127.

[80] J. Vischer, 'The concept of workplace performance and its value to managers', California Management Review, 49:2, 2006. p. 97.

[81] Adapted from Leesman ltd, 'The rise and rise of Activity Based Working, Reshaping the physical, virtual and behavioural workspace', 2017. p. 27. Retrieved on 20th April 2019. https://www.leesmanindex.com/The_Rise_and_Rise_of_Activity_Based_Working_Research_book.pdf

Table 10. Workplace impact [81]

physical features	activities features	service features
lighting control	individual focused in	IT service / helpdesk
air quality	planned meetings	restaurant / canteen
temperature control	phone conversations	refreshment facilities
noise levels	informal un-planned meeting	wifi network
general décor	collaborate on focused work	general cleanliness
desk space	audio conferences	general tidiness
meeting rooms	relax / take a break	remote access to work files
communal areas	reading	security
break-out zones	informal social interaction	hospitality services
accessibility	private conversation	health and safety provisions
privacy	collaborate on creative work	
plants and greenery	thinking / creative thinking	
different types of workspace	confidential discussions	
leisure onsite or nearby	learning from others	
	individual routine tasks	
	video conferences	
	hosting visitors	
	larger group meetings	
	individual focused out	
	spread out paper or materials	
	use specialist equipment	

2.4 Activity-based Workspaces

For those organisations interested in workspace effectiveness, the rise of activity-based working has led them to re-think the best possible working environment that could be designed to suit their employee's satisfaction. The employee's workspace becomes a matter of choice instead of a space the employee is anchored to. In activity-based work style, the employee is encouraged to seek a space with features designed in detail to facilitate the employee's activity. This is a clear departure from an assigned single desk or cubicle, which has ruled over the workspace floorplans for decades, forcing workers to spend their majority of working hours in the same space. It is perhaps a statement to the nature of the modern knowledge worker whose daily workflow encompasses a variety of different activities.

Although it may sound revolutionary to some, activity-based working has been around since the 1970's. Back then, American architect Robert Luchetti introduced the concept of "activity settings based environments" and "multiple settings to support the variety of performance modes". Early efforts to interpret activity-based working to the workspace architecturally were Barclays Capital Holdings by Sevil Peach architects and Interpolis by Erik Veldhoen architects in the eighties. In the late 1990's, both architects collaborated in the design of the new Microsoft Headquarter building in Amsterdam.

Activity-based working style also translate into employees embracing mobility during their worktime to a larger or a lesser degree. The table on the right hand side provides a details of the different types of user profiles in an activity-based workspace.

82 Adapted from Leesman ltd, 'The rise and rise of Activity Based Working, Reshaping the physical, virtual and behavioural workspace'. p. 12. Retrieved on 20th April 2019. https://www.leesmanindex.com/The_Rise_and_Rise_of_Activity_Based_Working_Research_book.pdf

Table 11. Activity-based working user mobility profile [82]

The camper / squatter	The timid traveller	The intrepid explorer	The true transient
I perform most/all of my activities at a single work setting and rarely use other locations within the office.	I perform the majority of my activities at a single work setting but also use other locations within the office	I perform some of my activities at a single work setting but often use other locations within the office	I use multiple work settings and rarely base myself at a single location within the office

Table 12. Architectural requirements of lowest and highest mobility profile

The camper / squatter	The true transient
- be able to personalise my workstation - do not like to have people walking past my workstation - like dividers between workstations - like personal storage space - prefer not too much art/photography - do not like to work when it is noisy	- have a variety of different types of workspaces - have break-out zones - do not like workspaces with fixed desktops - tea, coffee and refreshments facilities - good quality hospitality services - have communal areas - like nice décor - like a variety of different types of office lighting

[83] J. Turrell, 'Long Green', Turske and Turske, Zurich, 1991. p. 89.

" *My art deals with light itself.*

It's not the bearer of revelation - it is the revelation. " [83]

CHAPTER 3 LIGHTING AT THE END OF THE TUNNEL

3.1 Project Introduction of Callio

3.2 Spatial and Lighting Analysis of Retka

3.3 Design Process of Retka

3.4 Spatial and Lighting Analysis of Lab 2

3.5 Design Process of Lab 2

3.1 Project Introduction of Callio

3.1.1 Location

Pyhäsalmi Mine is located at the south-east side of Pyhäjarvi, a town in central Finland. Pyhäjarvi is 160 kilometres south of Oulu, 180 kilometres north of Jyväskylä and 350 kilometres north of Helsinki.

The site is two hours drive from Oulu, Jyväskylä and Kajaani airport and one and a half hours from Kuopio airport. From Kokkola and Vaasa harbour towns it is two hours or three hours forty-five minutes drive respectively. There are daily bus and train services from Helsinki.

The day length in Pyhäjarvi, Finland, is characteristically uneven throughout the year with nearly five hours of reported daytime during the winter solstice and more than twenty-one hours of daytime during the summer solstice. This is due to its northerly latitude of 63.6812° N, 25.9815° E.[84]

84 Latitude and longitude coordinates of Pyhäjarvi, Finland. Retrieved on 17th of April 2019. https://latitudelongitude.org/fi/pyhaejaervi/

85 Courtesy of Dr Andrew Marsh personal website. Retrieved on 17th of April 2019. http://andrewmarsh.com/apps/staging/sunpath3d.html

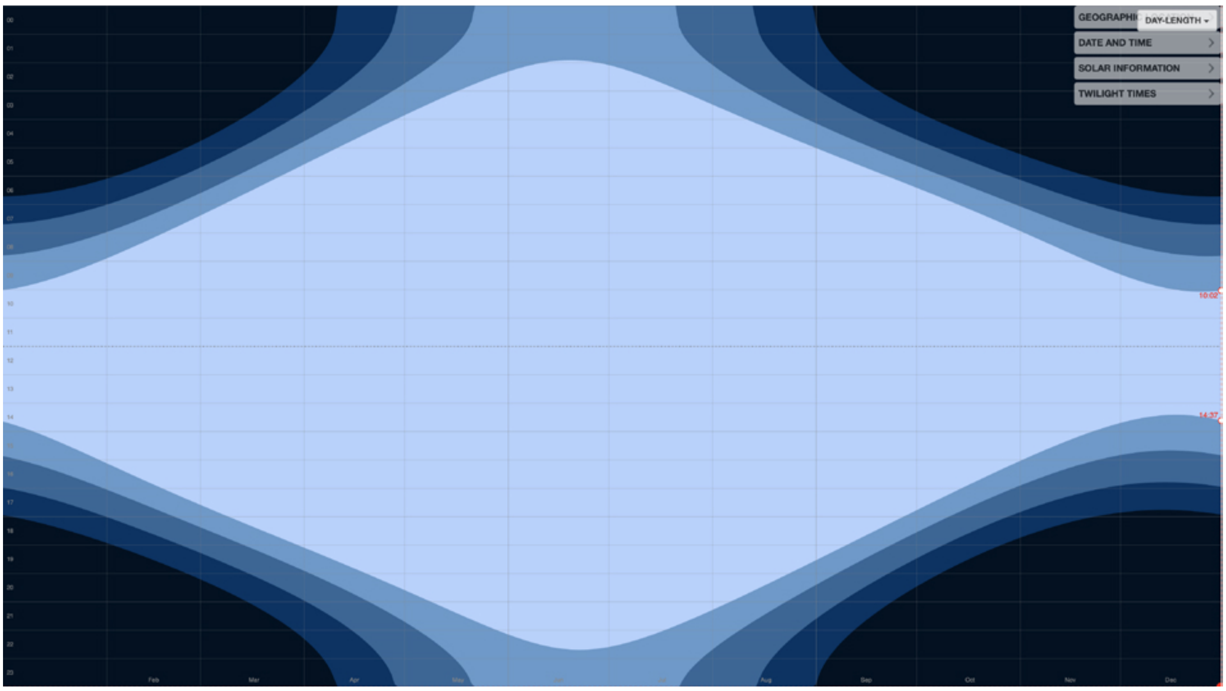


Fig. 11. Day length sun path for Pyhäsalmi [85]

Fig. 12. Transport connections to Pyhäjärvi [84]

3.1.2 History of Pyhäsalmi Mine

The Canadian giant First Quantum Mineral Ltd currently operates the mine under its Finnish subsidiary, Pyhäsalmi mine Oy. In 2017, the yearly production of copper accounted for 13,501 tonnes at an average ore grade of 1.1%.[86] By comparison, at 2,300 metres below ground, the largest underground copper mine and the sixth largest copper mine overall, El Teniente, in Chile, produced about 35 times more copper than Pyhäsalmi in 2017 alone.[87]

As the deepest working mine in Europe and the oldest in Finland, Pyhäsalmi mine's depth equals to four and a half times the height of Eiffel Tower, or nearly one and a half times the tallest building in the world, the almost completed Kingdom Tower.

Yet, the deepest mine in the world, Tautona Mine, is a little more than two and a half times deeper than Pyhäsalmi mine, followed by The Kidd Creek as the deepest base metal mine in the world at a little over twice the depth of Pyhäsalmi's.

86 Pyhäsalmi. (n.d.). Retrieved on 17th of April 2019 from https://www.first-quantum.com/Our-Business/operating-mines/Pyhasalmi/default.aspx

87 464,000 tonnes of copper at an average ore grade of 0.99%. CODELCO Operational and Financial Results December 31st, 2017. https://www.codelco.com/prontus_codelco/site/artic/20160404/asocfile/20160404163300/2017_yearendresults_analysis2_1.pdf

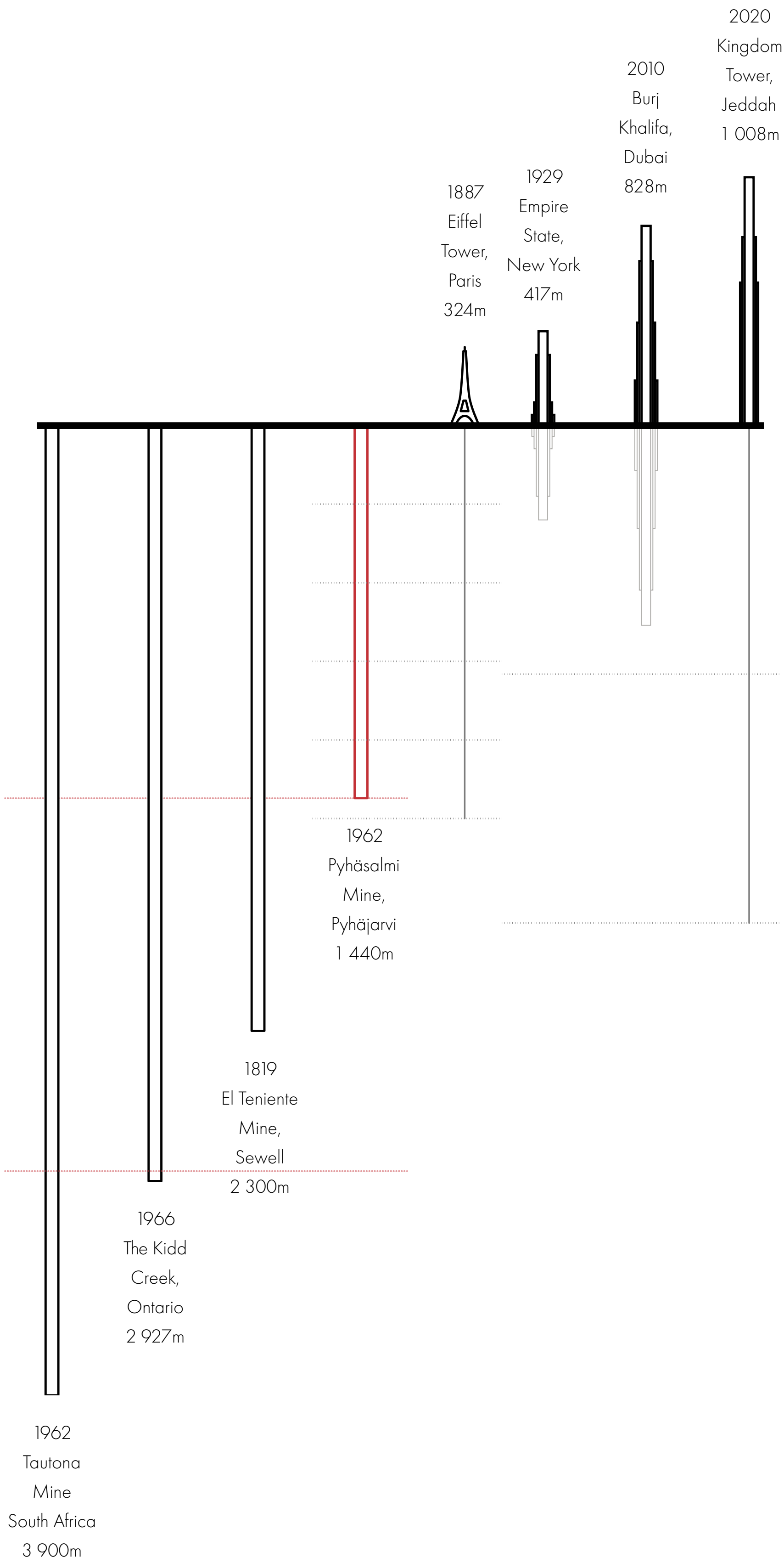


Fig. 13. High rises versus deep mines

The discovery of the subterranean metallic resources is attached to a local farmer in search for groundwater in 1958. In 1962, production began after the Finnish Ministry of Trade and Industry issued a permit granting the right to exploit the resource to Outokumpu Oy. Firstly, production occurred as open pit and later on activities moved underground as it became known that the new body of ore stretched below to depths of one kilometre.

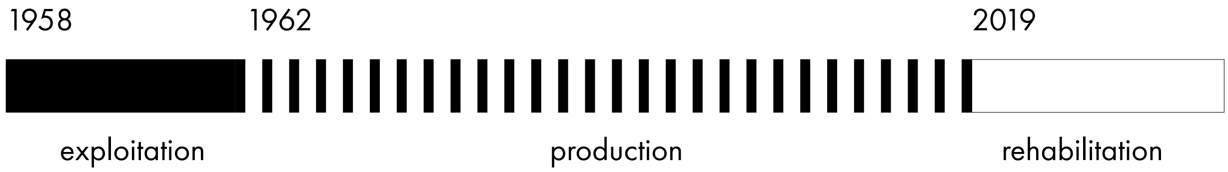


Fig. 14. Life-cycle of Pyhäsalmi Mine

The main three stages of the life-cycle of every mine is adapted from P. M. Heikkinen, P. Noras and R. Salminen, 'Mine Closure Handbook. Environmental Techniques for the Extractive Industries', Vammalan Kirjapaino Oy, Espoo, 2008

Generally, the duration of the production stage is subjected to not only to size and grade of the deposits, but also to the mining method used as well as the commodity price fluctuations in the stock market. In the case of Pyhäsalmi mine, it is very likely that underground mining will come to a halt by the end of 2019 according to resource estimates.

Fig. 15. Aerial view of Pyhäsalmi Mine
Courtesy of Callio.

1 *storage*
2 *heating plant*
3 *medical centre*
4 *administration*
5 *power station*
6 *workshop/storage*
7 *service/wash*
8 *storage*
9 *mineral processing plant*
10 *conveyor belt*
11 *hoist+tower/changing*
12 *refinery storage*
13 *ventilation plant*
14 *main outdoor storage*
15 *crude open pit*
16 *satellite mill*
17 *entrance tunnel to mine*
18 *backyard storage*
19 *dump-truck workshop*
20 *open pit*
21 *trailings dam*

Nowadays, the ground level of Pyhäsalmi Mine is comprised of an open pit (20), several building facilities and four trailings dams (21).

Ore that cannot be crushed underground is transported to the crushing mill (9). The crushed ore is then separated either by physical or chemical means inside the concentration plant (9) on site.

The resulting concentrate is transported to storage bins (8) by conveyor belt (10), before it is either transported by railway or road.

The waste generated during enrichment is transferred usually as slurry to trainings dam (21), or returned underground as backfilling material or in earthworks on site or elsewhere.

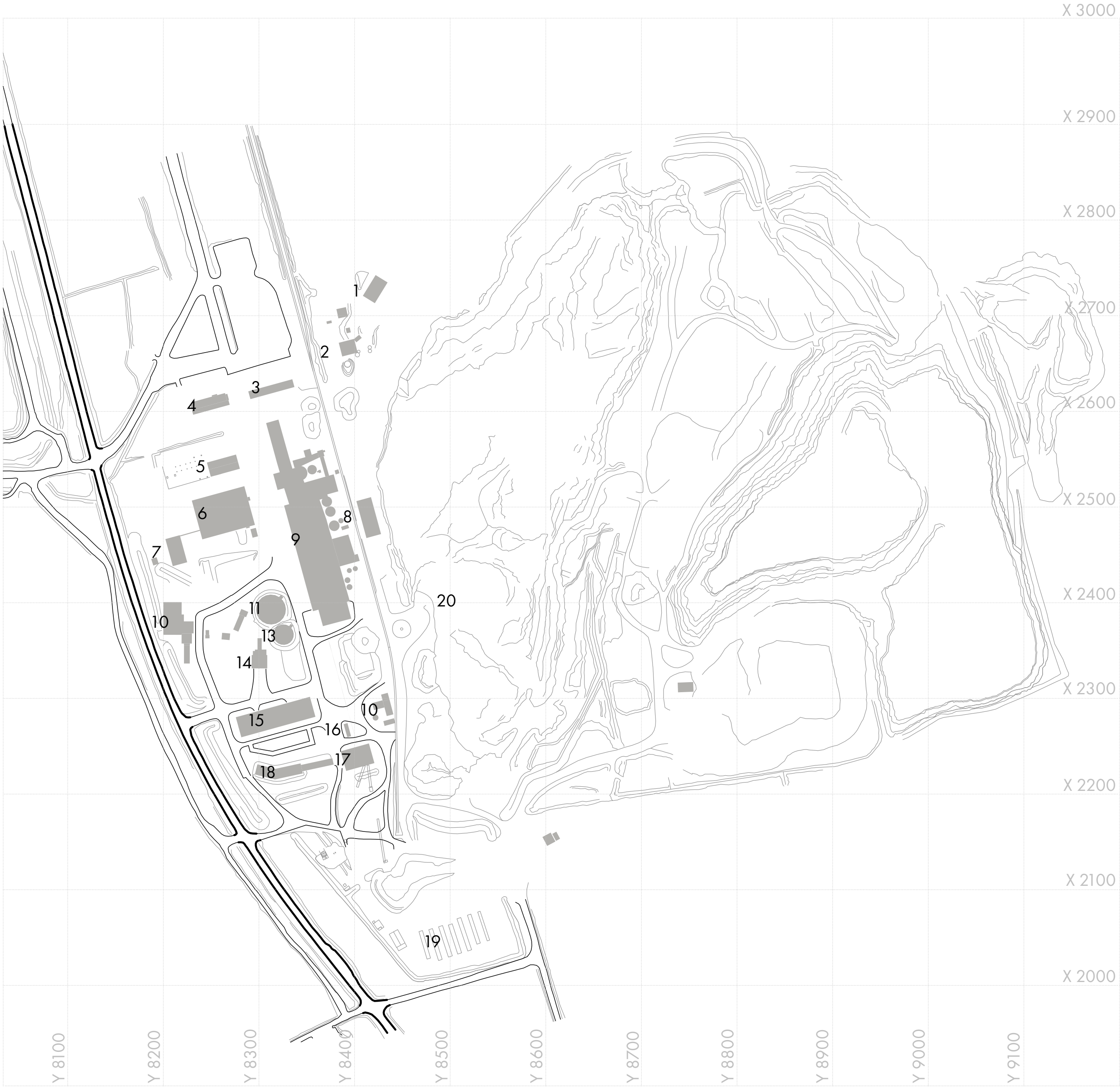


Fig. 16. Site plan of Pyhäsalmi Mine

Adapted from terrain in three dimensional drawing provided by the mapping team of First Quantum Minerals.

1	*storage*	8	*storage*	15	*crude open pit*
2	*heating plant*	9	*mineral processing plant*	16	*satellite mill*
3	*medical centre*	10	*conveyor belt*	17	*entrance tunnel to mine*
4	*administration*	11	*hoist+tower/changing*	18	*backyard storage*
5	*power station*	12	*refinery storage*	19	*dump-truck workshop*
6	*workshop/storage*	13	*ventilation plant*	20	*open pit*
7	*service/wash*	14	*main outdoor storage*		

Pyhäsalmi mine is divided into two sections: the old mine, from relative zero metres to -1,050 metres, and the new mine, from -1 050 metres to -1 410 metres.

The old mine can be travelled though via the Main shaft and Olli shaft or via decline by four-wheel drive or some individuals even cycle and run.

From 2001 to present, production has been concentrated in the new mine, from 1 050 to 1 410 metres deep, and can be reached the bottom via Timo shaft in three minutes or via decline in 40 minutes with a four-wheel drive or one hour and four minutes run depending on your level of fitness.

The main level at -1 410 metres concentrates the majority of activities. There is a restaurant called *Retka* (Finnish for *pickaxe*) where the mining operators flock in during breaks, a kitchen and adjacent three rooms for the surveyor, geologist and supervisors. Service halls at the main level provides access to the supervisor's office, buyer's office and the mechanics with a coffee room. There is a space for storage of tools and explosives. Additionally, there is parking space for four-wheel drives, fire engines and ambulances. Last, the car wash for all vehicles. The crusher is located at level -1 400 metres.

The main mining activities are drilling and charging either by drift or stope method. Scaling, surveying and loading the ore. Tunnels must be bolted and meshed and finally sprayed in concrete. Ventilation, water supply pipes and dam walls are installed. Finally, the electrical system is run throughout.

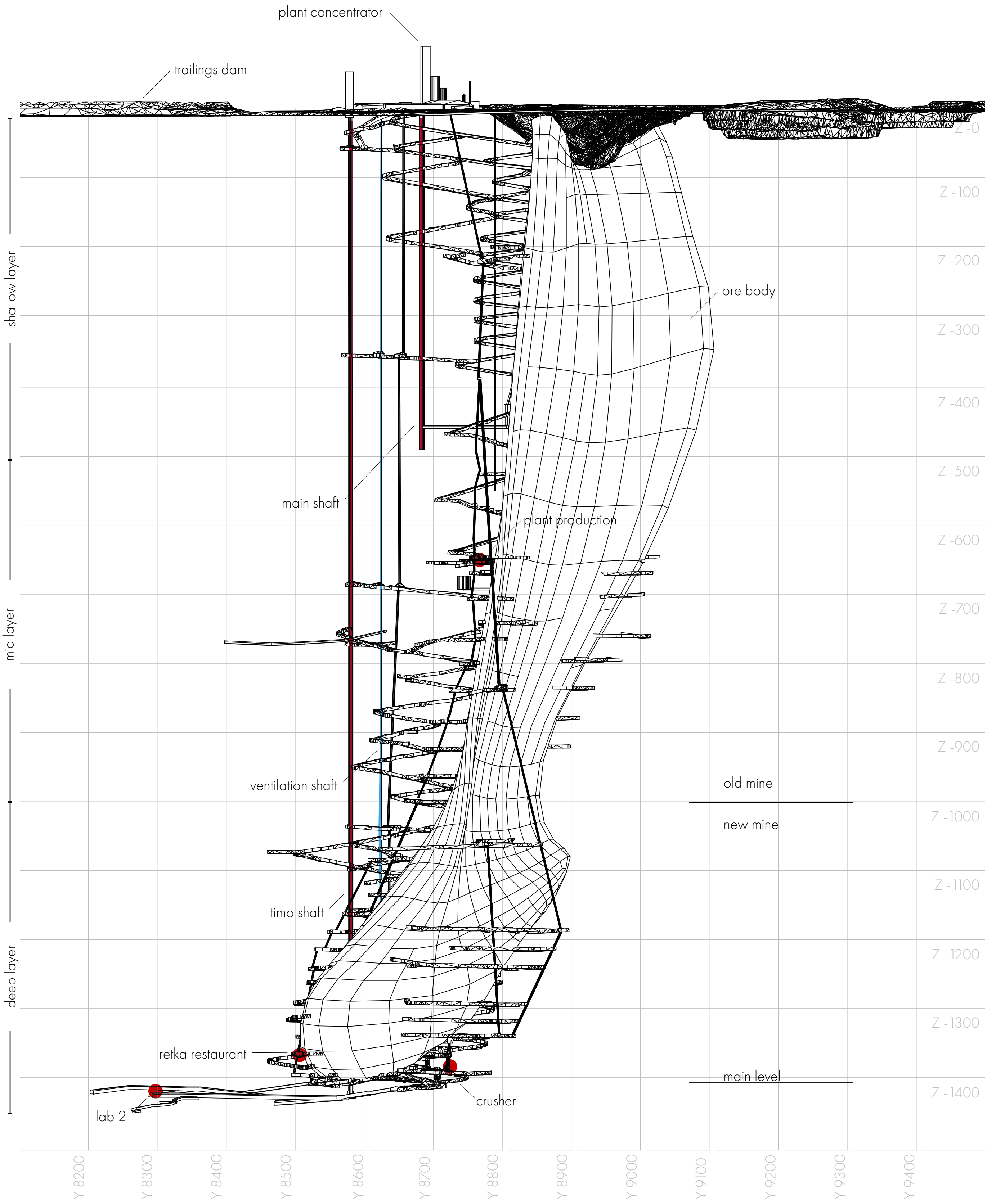


Fig. 17. Pyhäsalmi Mine elevation

3.1.3 Main Level - a photographic reportage

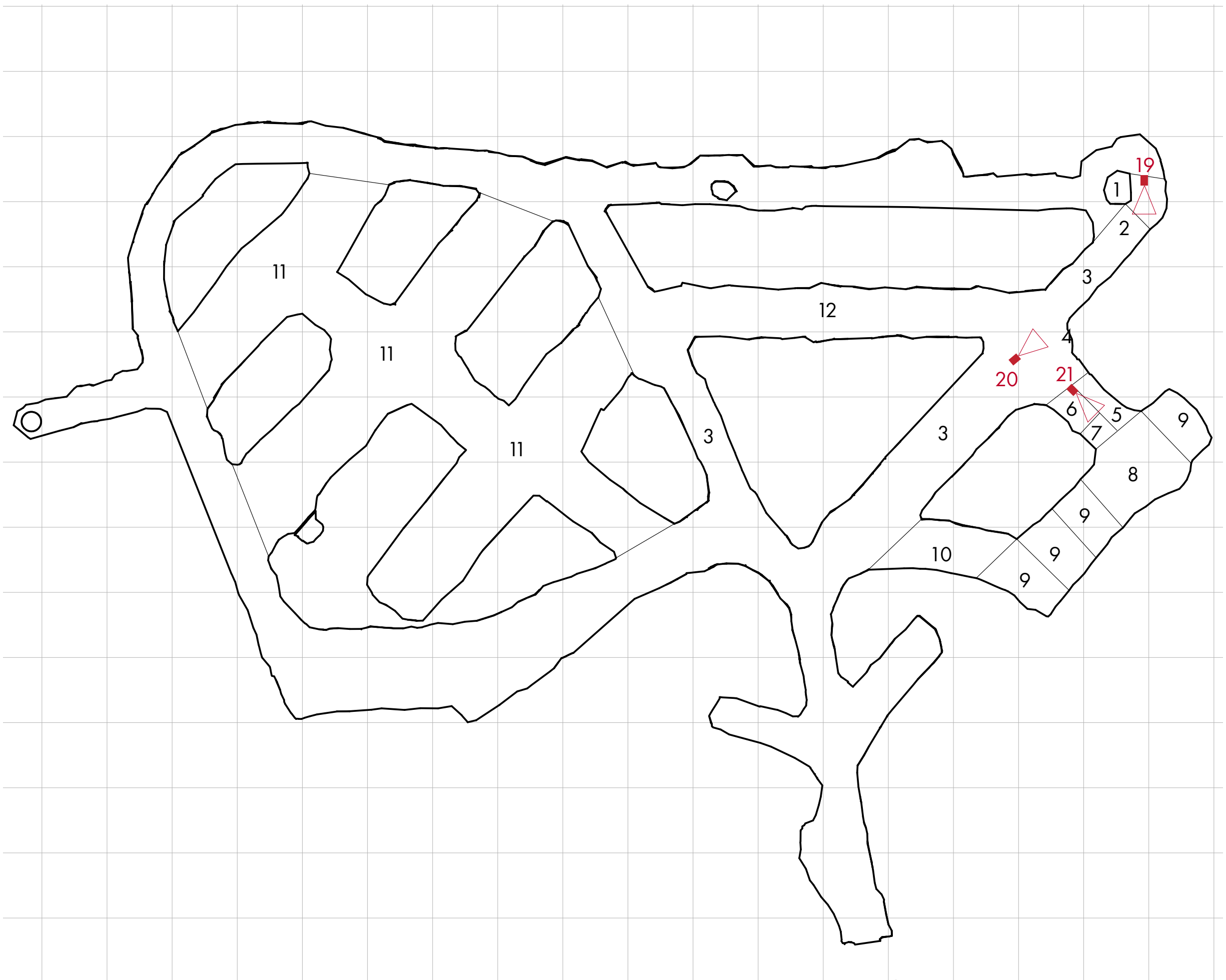


Fig. 18. Floor plan of the Main Level at 1 410 m below ground

1	*timo shalf*	5	*cloak room*	9	*office*
2	*lift lobby*	6	*toilets*	10	*storage room*
3	*corridor*	7	*kitchenette*	11	*service room*
4	*smoking booth*	8	*retka restaurant*	12	*car park*

Fig. 19. Timo shaft landing room

Fig. 20. Corridor leading to Retka restaurant

Fig. 21. Corridor leading to Retka restaurant

3.1.4 Lab 2 Level - a photographic reportage

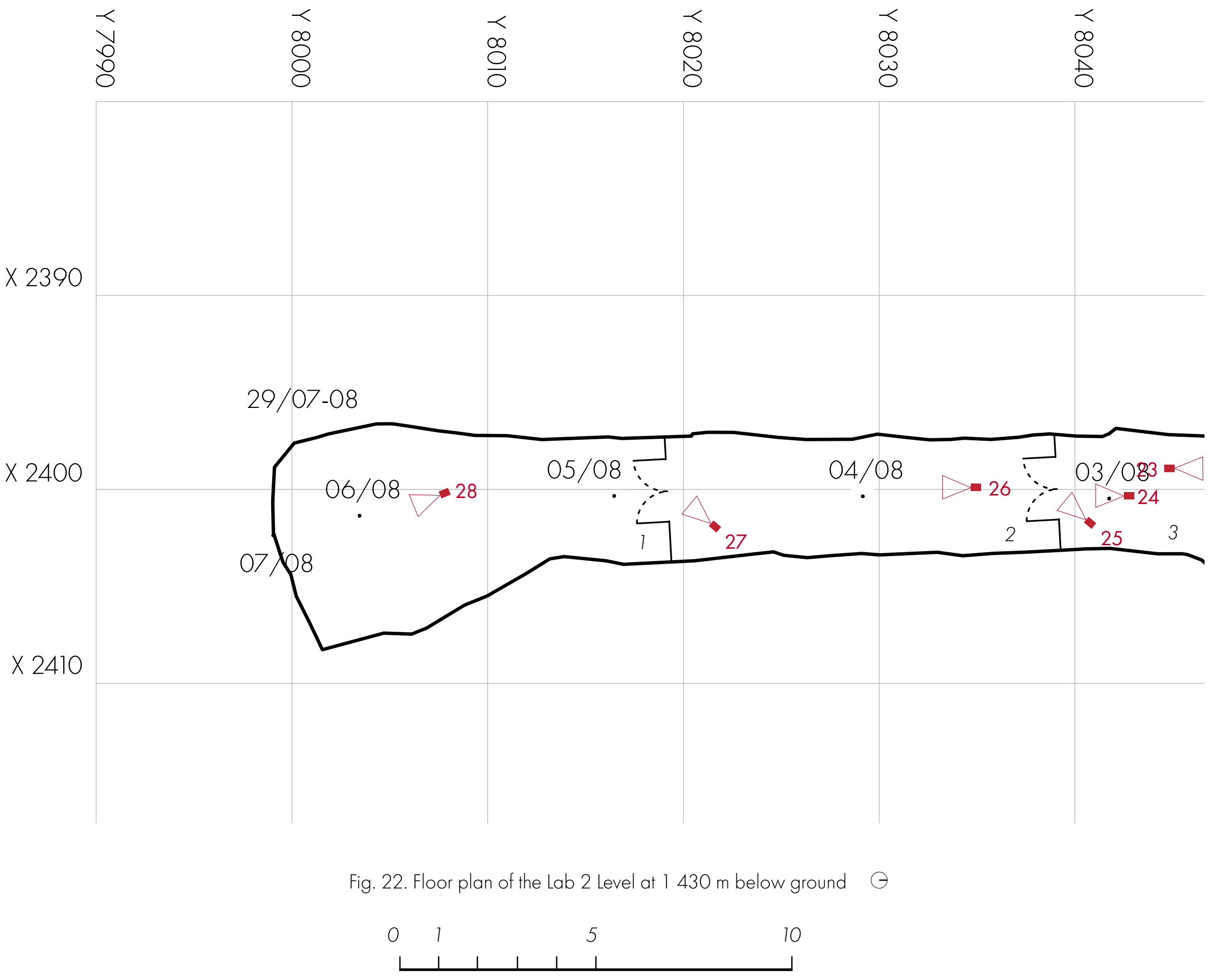


Fig. 22. Floor plan of the Lab 2 Level at 1 430 m below ground

1 *Lab 2*   2 *storage room*   3 *tunnel*

Fig. 23. 4x4 vehicle parked in front of Lab 2

Fig. 24. Tunnel to Lab 2

Fig. 25. First set of doors of Lab 2

Fig. 26. Storage room of Lab 2

Fig. 27. Second set of doors of Lab 2

Fig. 28. Back wall of Lab 2

3.1.5 Programme Overview

The universities of Oulu and Jyväskylä together with the municipality of Pyhäjarvi and Pyhäsalmi Mine Oy founded Callio in order to plan the rehabilitation of Pyhäsalmi mine upon termination of the mining operations. At present, Callio is part of the regional development programme of the Kerttu Saalasti Institute, University of Oulu. In 2017, Callio joined the Baltic Sea Underground and Innovation Network ("BSUIN"). The following six underground laboratories are also part of the BSUIN (by order - deep to shallow): Callio in Pyhäsalmi mine, Finland; Äspö Hard Rock Laboratory in Oskarshamn, Sweden; Conceptual Lab development co-ordinated by KGHM Cuprum R&C centre, Poland; Khlopin Institute Underground Laboratory, Russia; Ruskeala, Russia.

At present, Callio operates as the overarching project that manages the infrastructural transfer to businesses and scientific research organisations. Businesses can directly contact Callio project managers to enquire about the facilities. For scientific research purposes, there is a sub branch called Callio Lab.

The 2025 vision for Pyhäsalmi mine presents a fully functioning facility equipped with optimal infrastructure in order to host around ten different types of operations and an estimate number of users working on site or remotely or visiting from time to time. The table on the right hand side illustrates the data collected from an email that was sent to the Callio's project coordinator, Sakari Nokela, and Kerttu Saalasti's project manager, Jari Joutsenvaara, on the 10th of December 2018.

Table 13. User programme

activity type	user type		number of users	
	fixed	flexible	lab 2	callio
scientific research	researcher	-	(4)	50-100
energy storage	technician	-	-	2-4
data centre	engineers	-	-	0-20
farming	biologist / farmer	-	(2)	2-30
machine testing	engineer	-	-	20
geo-energy	engineer	-	-	2-20
tourism	-	visitor / guide	(100)	2500
food storage	operator	inspector	-	2-10
training	-	teacher / student	(4)	60-200
ore refinery	engineer / chemist	-	-	5-50

Total number of users estimated per year 123 - 2 954

3.1.6 Programme Specification

According to 'Table 14: User programme', it has been estimated that there will be between 123 to 2954 users per year. These users can be working on site or working remotely or simply on a site visit. This data enables me to simply identify the type and quantity of users that may spend some time in Callio. Most importantly, I can anticipate which activities are associated to each user group and their related spatial and lighting requirements.

This thesis is centered around the adaptive and intelligent lighting of two spaces in Callio: Retka restaurant and Lab 2. Further detailed information about the functionality of each space is required in order to set a clear intentions and instructions to realise the lighting design.

Retka restaurant is a mixed use space with the same operating hours as Callio. A comprehensive detailed space programme sheds light upon its public nature of use. It ranges from fixed spaces, such as the food counter, to flexible spaces with portable furniture leaving open the possibility of different ways to organise the space or create lighting atmospheres.

Lab 2 is an experimentation room to suit the needs of researchers and business people. As such, experimentation is the main activity which can be realised utilising testing devices or computer. It should provide an atmosphere of collaboration but also privacy and quietness are important in such workspaces.

As a whole, this programme specification shall provide the terms of reference upon which the design task at hand will develop rather than a strict project brief.

Table 14. Retka programme specification

mixed use as an information centre and canteen

detailed space programme	fixed or flexible	area - m^2
food service	fixed	20
locker	fixed	4
bar	flexible	28
dining	flexible	40
café	flexible	20
lounge	flexible	16
booth	flexible	8
couch	flexible	12
circulation		42
Total floor area		190

Table 15. Lab 2 programme specification

fixed use of researchers and business people

detailed space programme	fixed or flexible	area - m^2
experimentation	fixed	35
desk work	fixed	34
meeting	flexible	28
break	flexible	9
workshop	flexible	21
cloakroom	fixed	5
circulation		36
Total floor area		168

3.2 Spatial and Lighting Analysis of Retka

3.2.1 Current condition of Retka

The subterranean restaurant is named after the Finnish word "*retka*", which can be translated as "*pickaxe*" or "*picks*", a tool used in mine craft. Retka restaurant is located on the main level at 1 410 metres below ground level. It can be reached by lift boarding the Timo Shaft and a one hundred metres walk.

The corridor leading to the restaurant gives way to the restrooms and the kitchen on the right hand side wall and the clothes racks along the left hand side wall are used by the mine personnel to hang their equipment. There are six rooms that can be accessed directly from the restaurant: the control room being the largest, a kitchenette, a storage room and three offices, one with a door to a sauna. This sauna is the world's deepest sauna to date. The main customers are the mine personnel but it is open to all visitors. Mine personnel usually spend their scheduled breaks in the restaurant sitting on chairs around a table. There are twelve four-seat tables in Retka restaurant. Additionally, there are two vending machines serving hot drinks. During lunch and dinner hours the restaurant service offers a hot meal which is cooked in the facilities above ground level. The kitchenette annexed to the restaurant is only used to heat up food and wash dishes. On the opposite side of the food counter, there is a computer station with three laptops and one more desktop computer in the opposite wall. There are notice boards, lockers and flat televisions screens scattered along the walls of the restaurant. This is a multi-functional space where not only eating occurs, but also training or simply taking time to relax. Other uses of the space outside meal service include training, information point for visitors or even concerts have been hosted in the past.

The design of Retka restaurant is focused on the maximum seating capacity as opposed to creating an atmosphere through interior design. The national radio plays in the background as an inexpensive option for a casual atmosphere.

When the current users of Retka were interviewed, they expressed both positive and negative opinions about the space. The positive comments were that Retka feels "nice, cosy, homely, peaceful, warm" with "even lighting on tables" and food is displayed with "pleasant light in food counter" and as one enters Retka there is somehow "pleasant low lighting as one comes from darker spaces". While the negative comments were many and varied. Users wished that it was possible to "dim lights when presenting" and "brighter lights when reading". In general the lighting is "uneven" and the space feels "too dark" and "too warm that could make one fall asleep", "not exciting and arousing atmosphere" and those "dark corners are scary". The "suspended ceiling makes the space feel low" and it would be useful to have "lights on the wall" to better see posted notices.

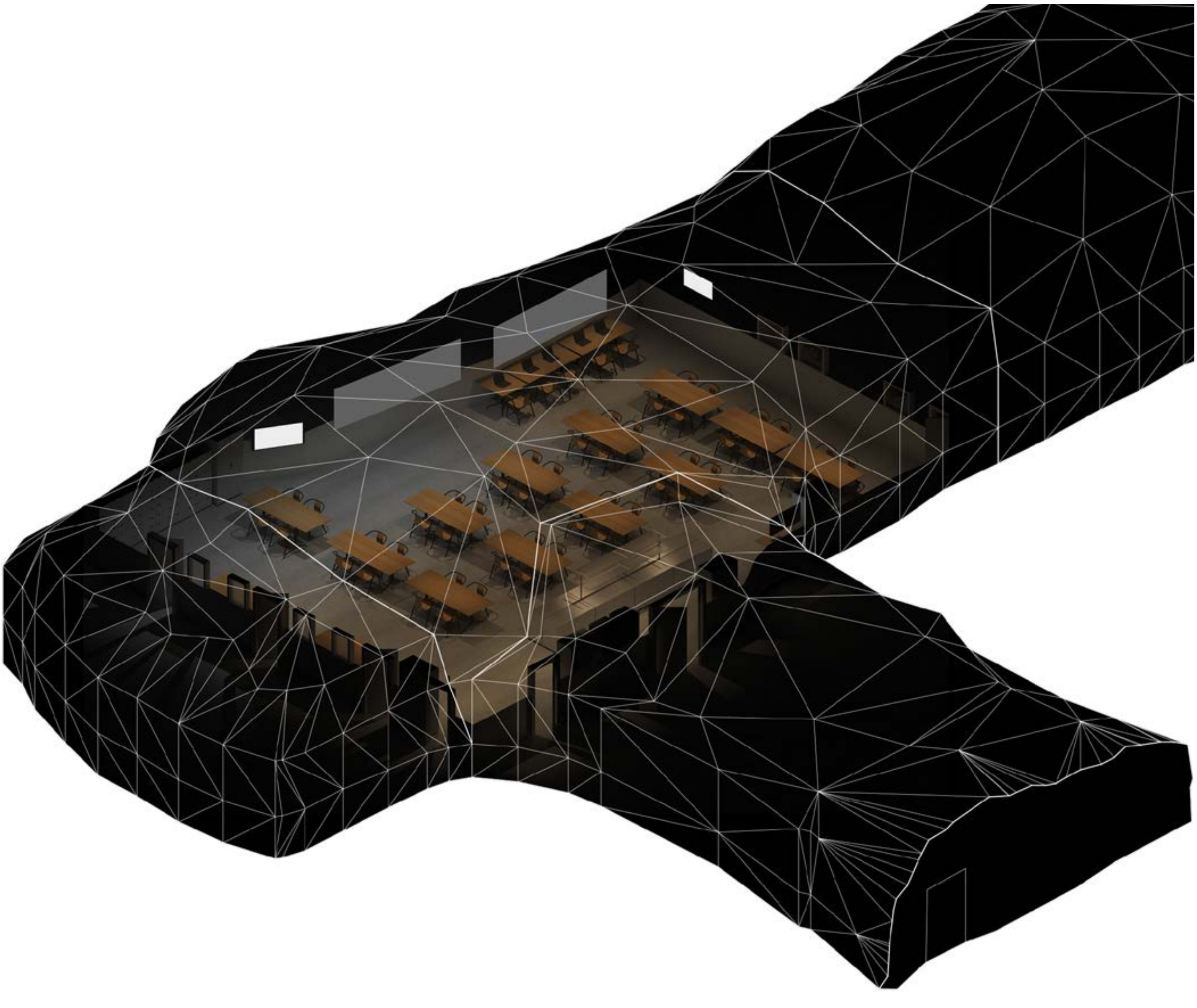


Fig. 29. Isometric view of Retka

Retka restaurant's surface area is 190 square metres and the suspended ceiling is at 2.8 metres high covering the real height of the space. This illustration presents the current lighting condition and furniture layout in an three dimensional isometric view.

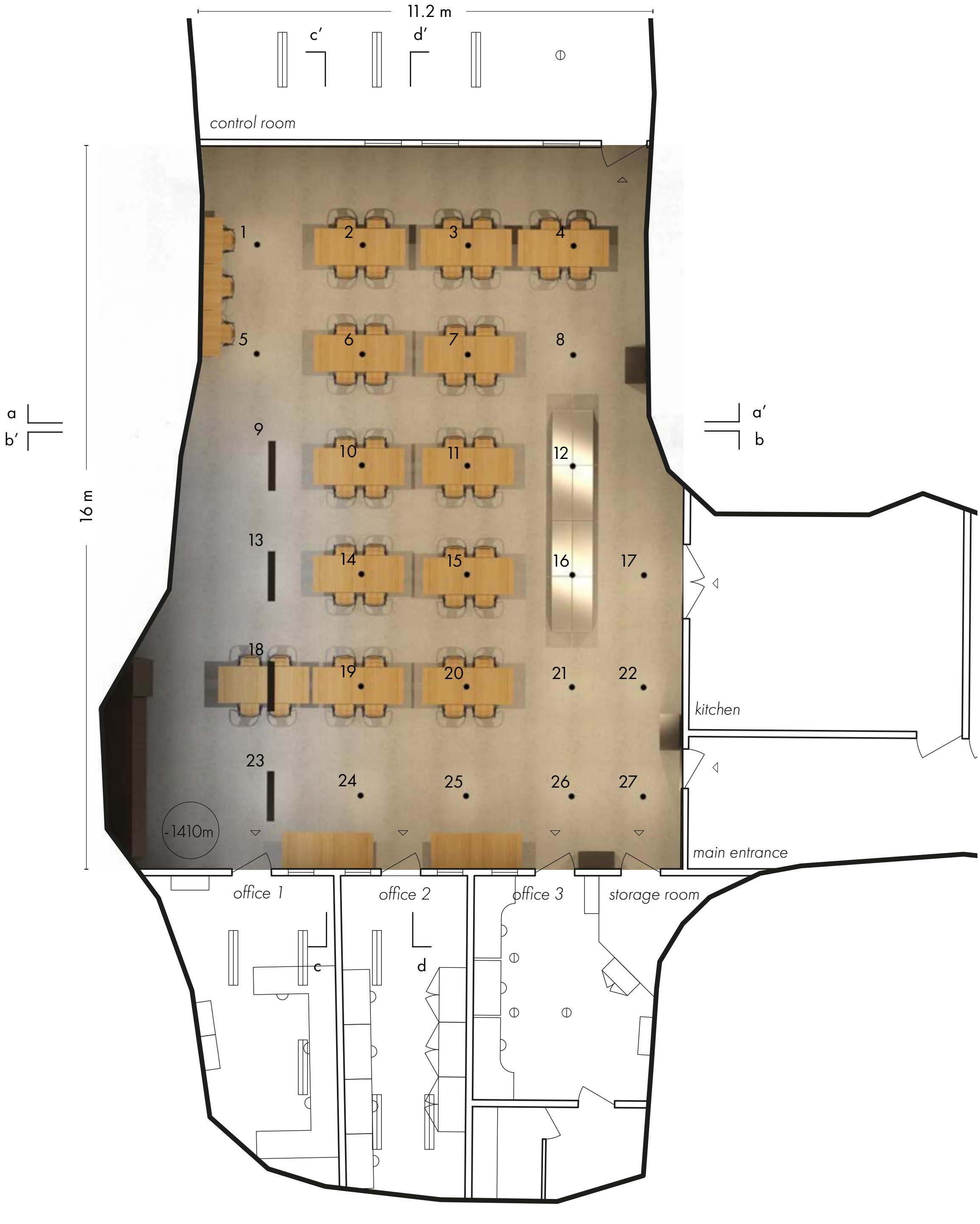


Fig. 30. Plan view of Retka restaurant

0 1 2 3 4 5 10

This plan view presents the current layout and lighting condition of the Retka restaurant.
There are twenty-three downlights distributed evenly in the area. There are four additional lineal lights that are dimmable.

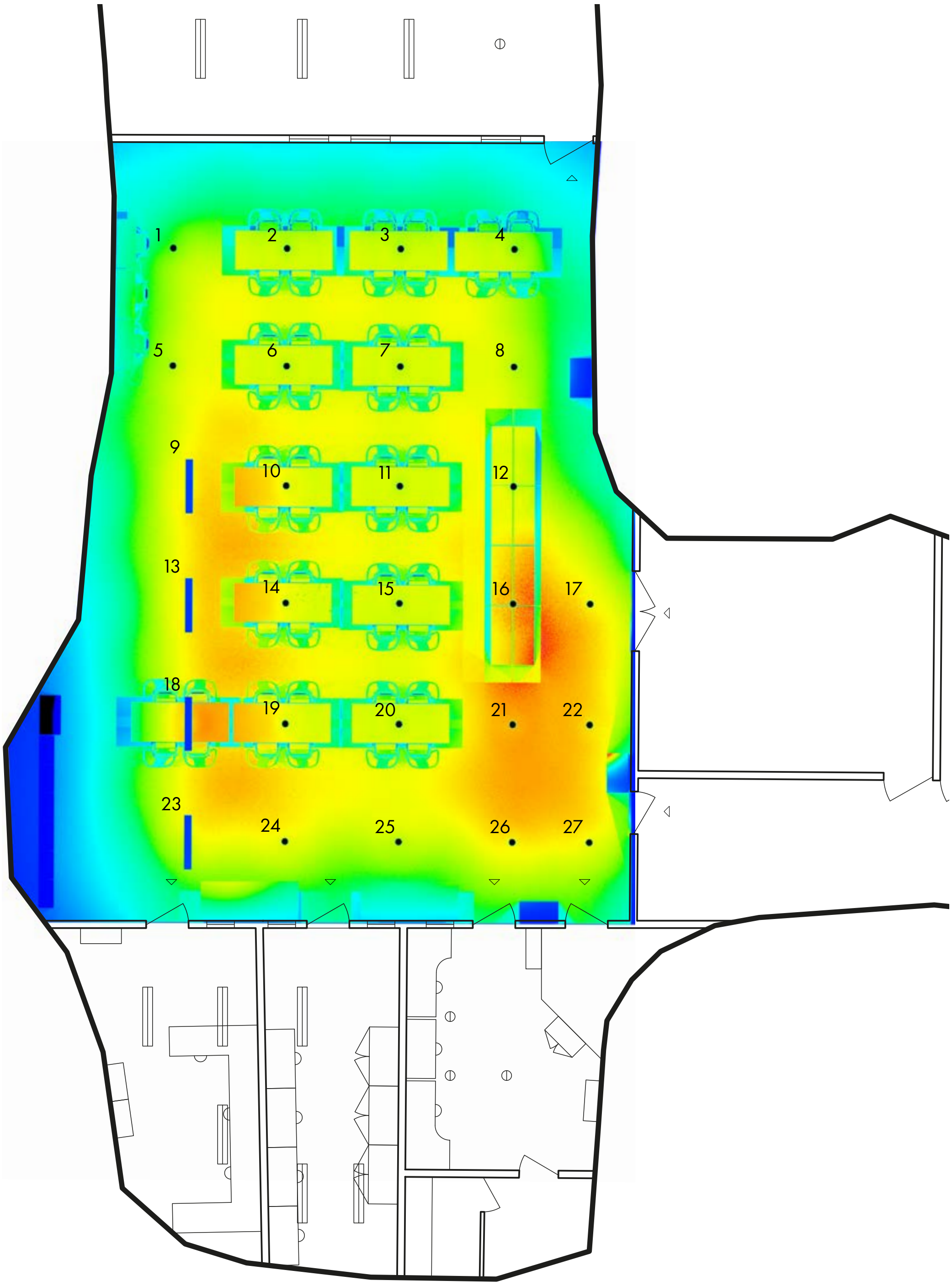
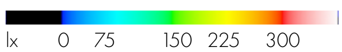


Fig. 31. Illuminance analysis map of Retka



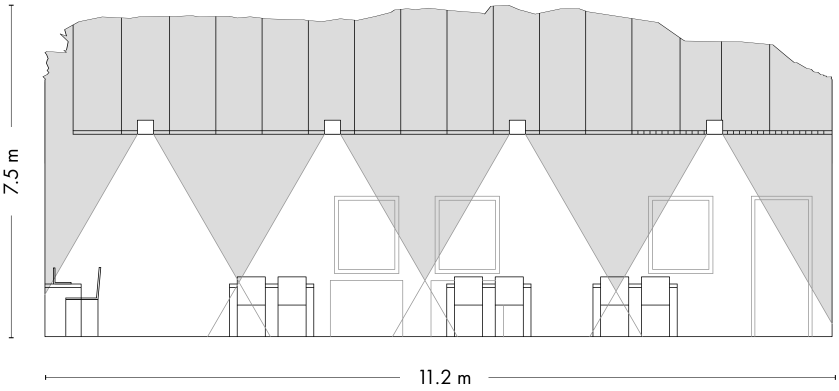


Fig. 32. a-a' section of Retka

0 1 2 3 4 5 10

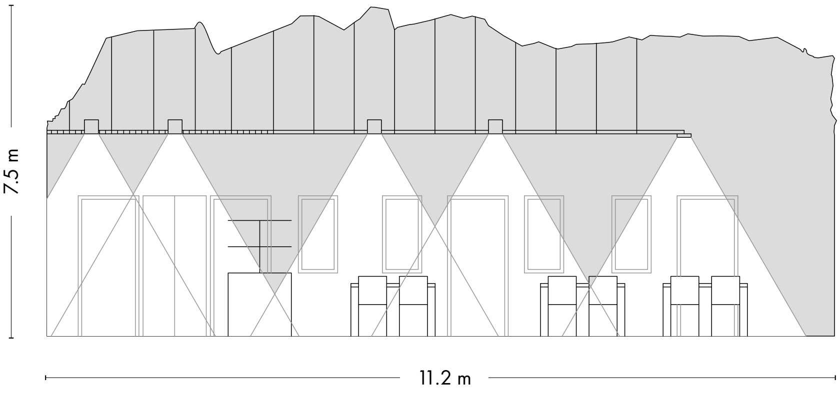


Fig. 33. b-b' section of Retka

0 1 2 3 4 5 10

Fig. 34. Food counter of Retka

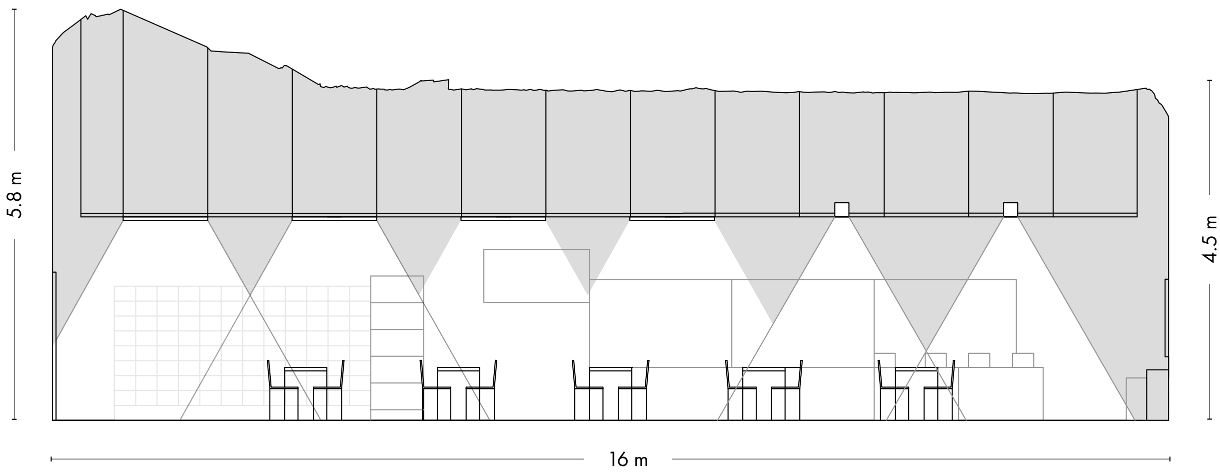


Fig. 35. c-c’ section of Retka

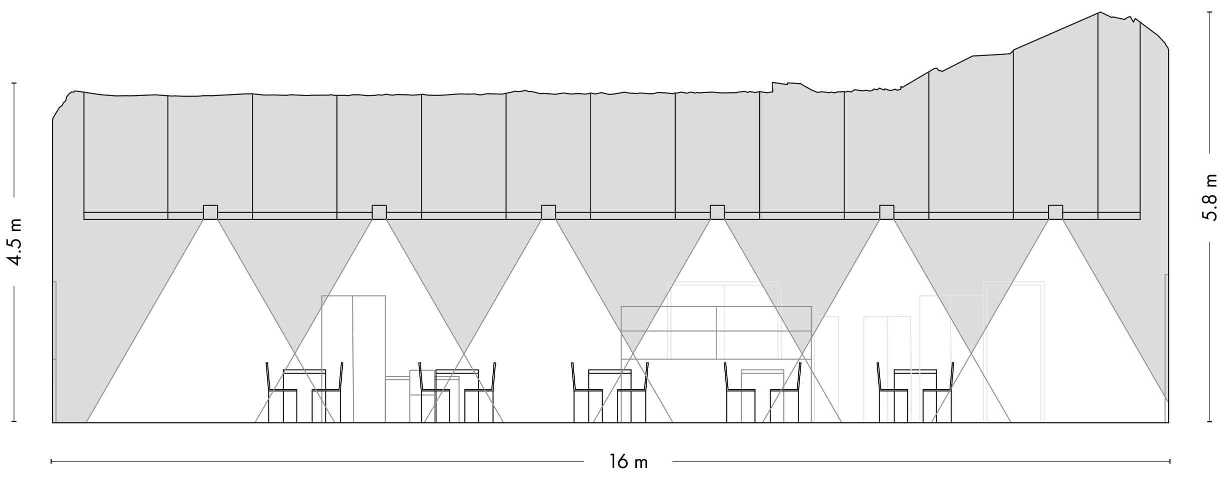


Fig. 36. d-d’ section of Retka

Fig. 37. Diagonal view of Retka

3.3 Design Process of Retka

3.3.1 Study on plan

As of today the existing space of Retka restaurant offers restricted spatial flexibility. The lighting is limited to recessed ceiling downlights in an uncompromising grid pattern. The new proposed layout is inspired in the public to private dichotomy. Thus, the main entrance corner represents the most public area with bar seating configuration whereas the opposite corner offers the most intimate space with booth seating. This differentiation of heights in seating and table and chair widths allows for a greater variety of uses. Lighting works cohesively with all the other elements architecturally in order to create the light distribution and intensity that the space and user requires.

Fig. 39. Concept section of Lab 2

Luminaire symbols used in the reflected ceiling plans.

1 in-ground wall washer

2 suspended track with point light sources

3 suspended track with integrated uplight

4 track-mounted directional spotlight with glare shield

5 track-mounted asymmetrical wallwasher

6 track-mounted pendant luminaire

7 track-mounted projector

8 track-mounted uplight, asymmetrical

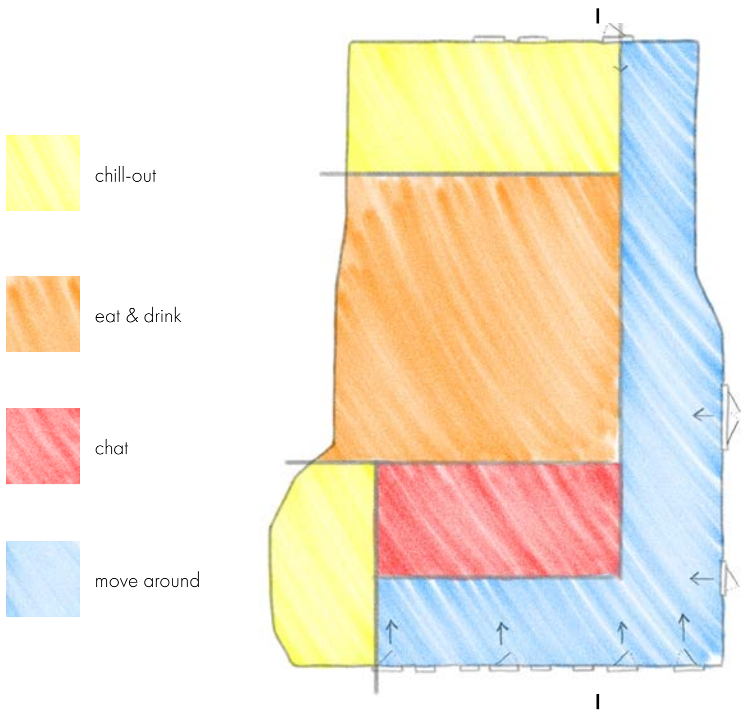


Fig. 38. Concept of spatial zones for Retka

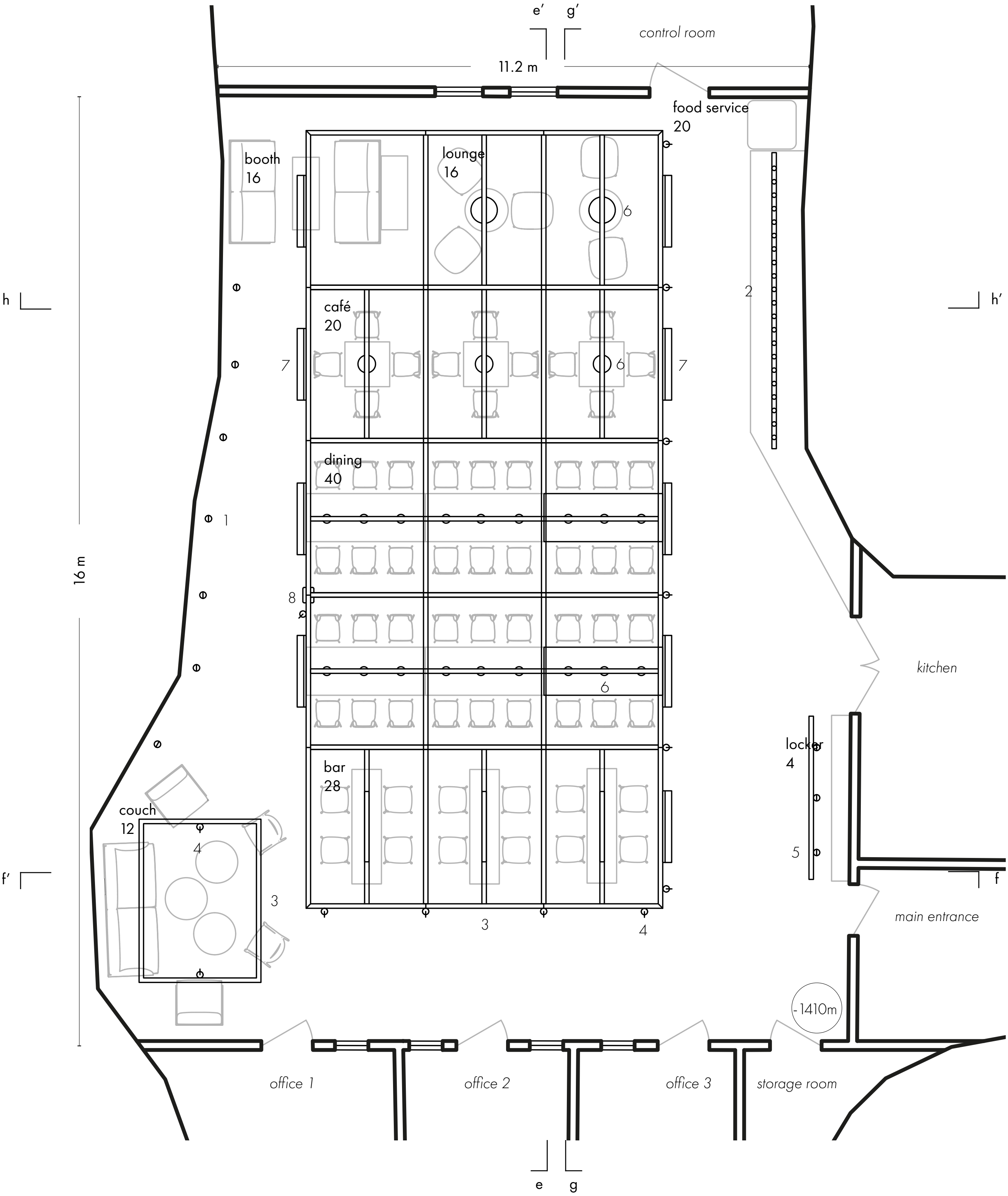


Fig. 40. Proposed reflected ceiling plan for Retka

3.3.2 Study on section

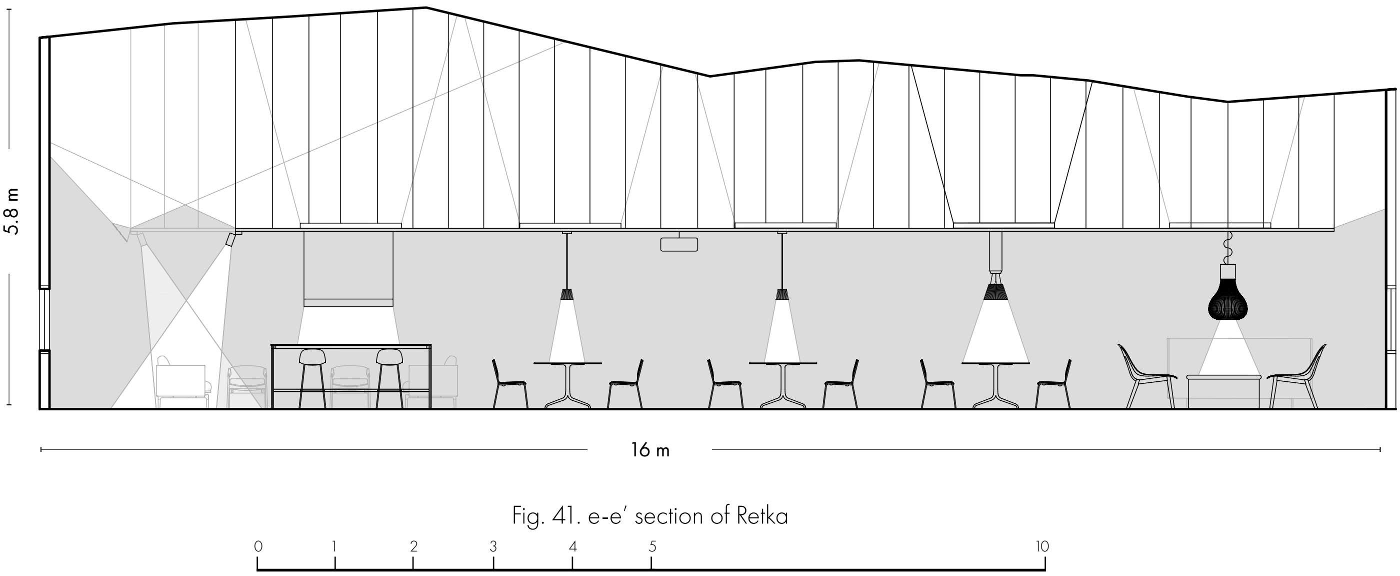


Fig. 41. e-e’ section of Retka

The lighting track system suspended from the ceiling to a height of 2.8 metres from the floor level, combines the flexibility to install luminaires at any desired point with the visual comfort of the indirect light. The LED module is mounted flush on the top side of the track, projecting light onto the ceiling.

From left to right: Wide flood spotlights with glare shield illuminate the couch area. Oval wide flood and lineal pendant luminaires illuminate the bar area. Spotlights project light onto tabletops in the dining area. Finally, designer pendant luminaires emit wide beam light on the tabletops in the lounge area.

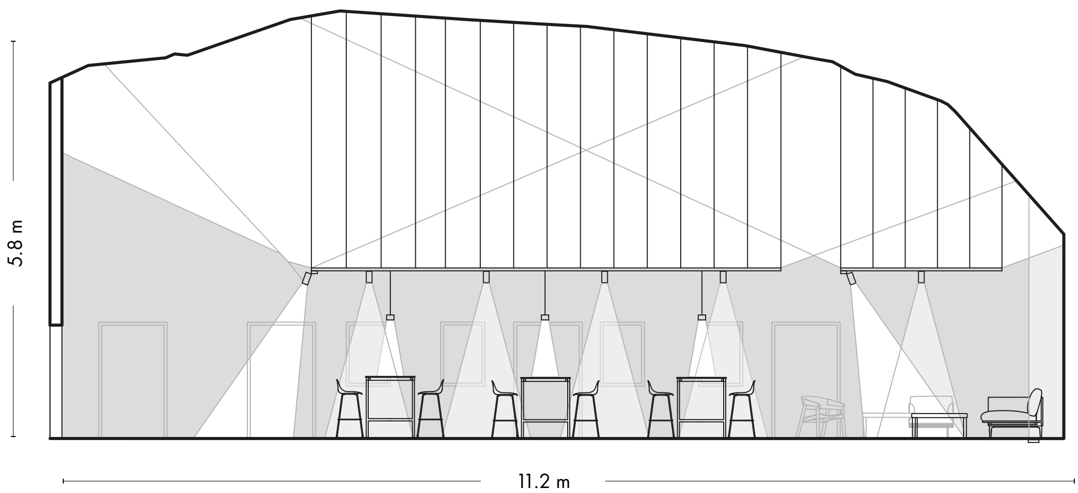


Fig. 42. f-f’ section of Retka

From left to right: Wide flood spotlights with glare shield illuminate floor in the circulation area. Oval wide flood and lineal pendant luminaires illuminate the bar area. Wide flood spotlights project light onto coffee tables in the couch area. The feature wall is illuminated with a wall wash.

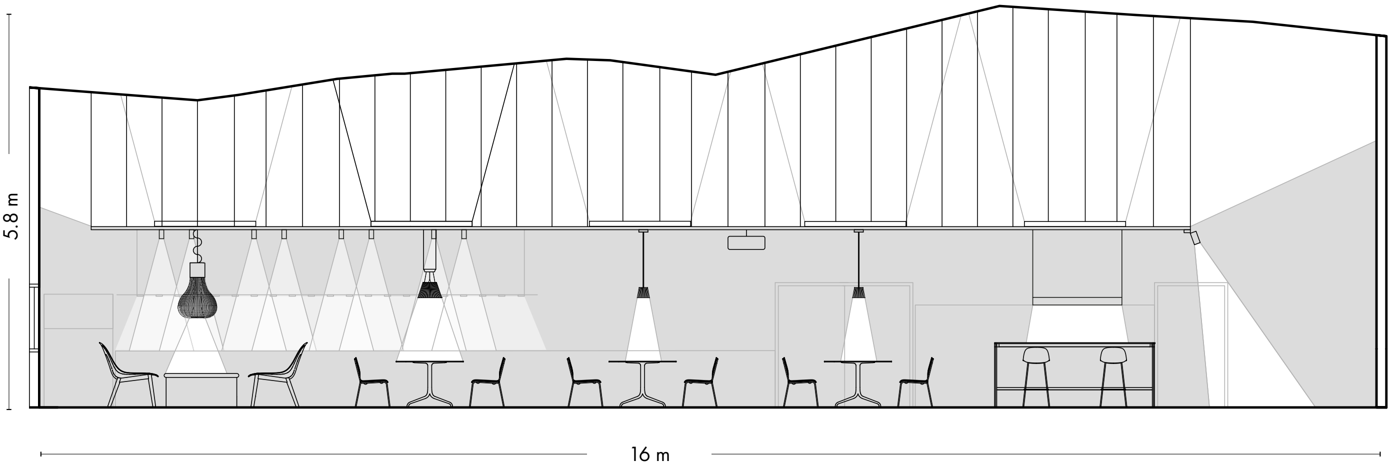
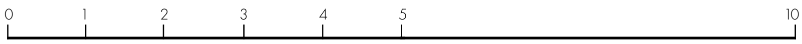


Fig. 43. g-g' section of Retka



From left to right: Designer pendant luminaires emit wide beam light on the tabletops in the lounge area. Spotlights project light onto tabletops in the dining area. Oval wide flood and lineal pendant luminaires illuminate the bar area. Spotlights with glare shield project light onto the floor in the circulation area.

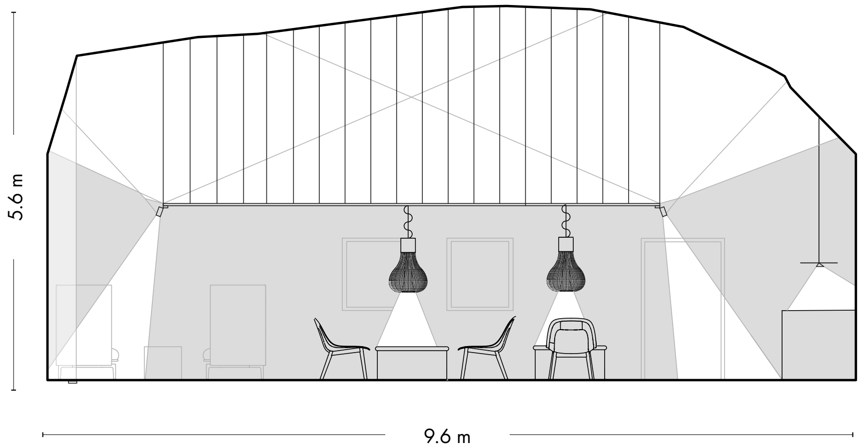
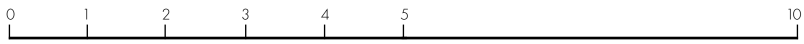


Fig. 44. h-h’ section of Retka



From left to right: Wide flood spotlights with glare shield illuminate floor in the circulation area. Designer pendant light emit wide beam light on the tabletops in the lounge area. Point light sources mounted onto the hood lit up the food counter.

3.4 Spatial and Lighting Analysis of Lab 2

3.4.1 Current condition of Lab 2

At present there are ten operational deep underground laboratories in the world. In the field of physics, conducting experiments in such laboratories has enabled scientists to monitor low environmental background radiation components such as atmospheric muons, neutrons in rock and concrete lining, nuclear decays in the environment, radon as well as temperature and humidity.[88]

Low environmental background radiation is needed for the study of low energy phenomena, such as proton decay or double beta decay, or rare interaction of particles, such as neutrinos and dark matter.[89] The study of these phenomena and behaviour of particles aims to provide answers to the knowledge gap in the Standard Model of particle physics, such as what dark matter really is or what happened to the antimatter during the early stages of the Universe, among others.[90]

Lab 2 is a deep underground measuring hall inside Pyhäsalmi mine at 1 430 metres below ground level and around 4 000 m.w.e. of rock overburden made of volcanogenic massive sulphide ore body. Lab 2 was originally built in 2005 as an exploration tunnel based on the design requirements of Large Apparatus studying Grand Unification and Neutrino Astrophysics (LAGUNA) experiment together with the construction know-how of Pyhäsalmi Mine.

It was then finished in concrete floors as well as shortcreted walls and ceiling reinforced with four kilometre long rock bolts used to improve stability and load bearing capacity of the rock mass. The 120 square metres experimental hall can be accessed through two double swing steel gates which divides the tunnel in two halls. The first gate and hall act as buffer zone in case of explosion or fire breach. The air exchange of Lab 2 is currently at a rate of 10 m^3/s through a ventilation duct made out of polyester base fabric. The average temperature is 26 degrees Celsius and a humidity of 55 - 66 per cent.[91]

88 A. Bettini, 'New underground laboratories: Europe, Asia and the Americas', Physics of the Dark Universe, vol. 4, September 2014. p. 36 - 40.

89 J. Joutsenvaara, 'Deeper understanding at Lab 2 : the new experimental hall at Callio Lab underground centre for science and R & D in the Pyhäsalmi Mine, Finland', Master's Thesis, University of Oulu, 2016. p. 6.

90 European Organization for Nuclear Research, 'The Standard Model', European Organization for Nuclear Research, Switzerland, 2019, https://home.cern/science/physics/standard-model, (accessed 2 January 2019).

91 Callio Lab, 'Current Underground Research Facilities', Callio Lab, 2019, https://calliolab.com/facilities-2/currently-available-facilities/ (accessed 3 January 2019).

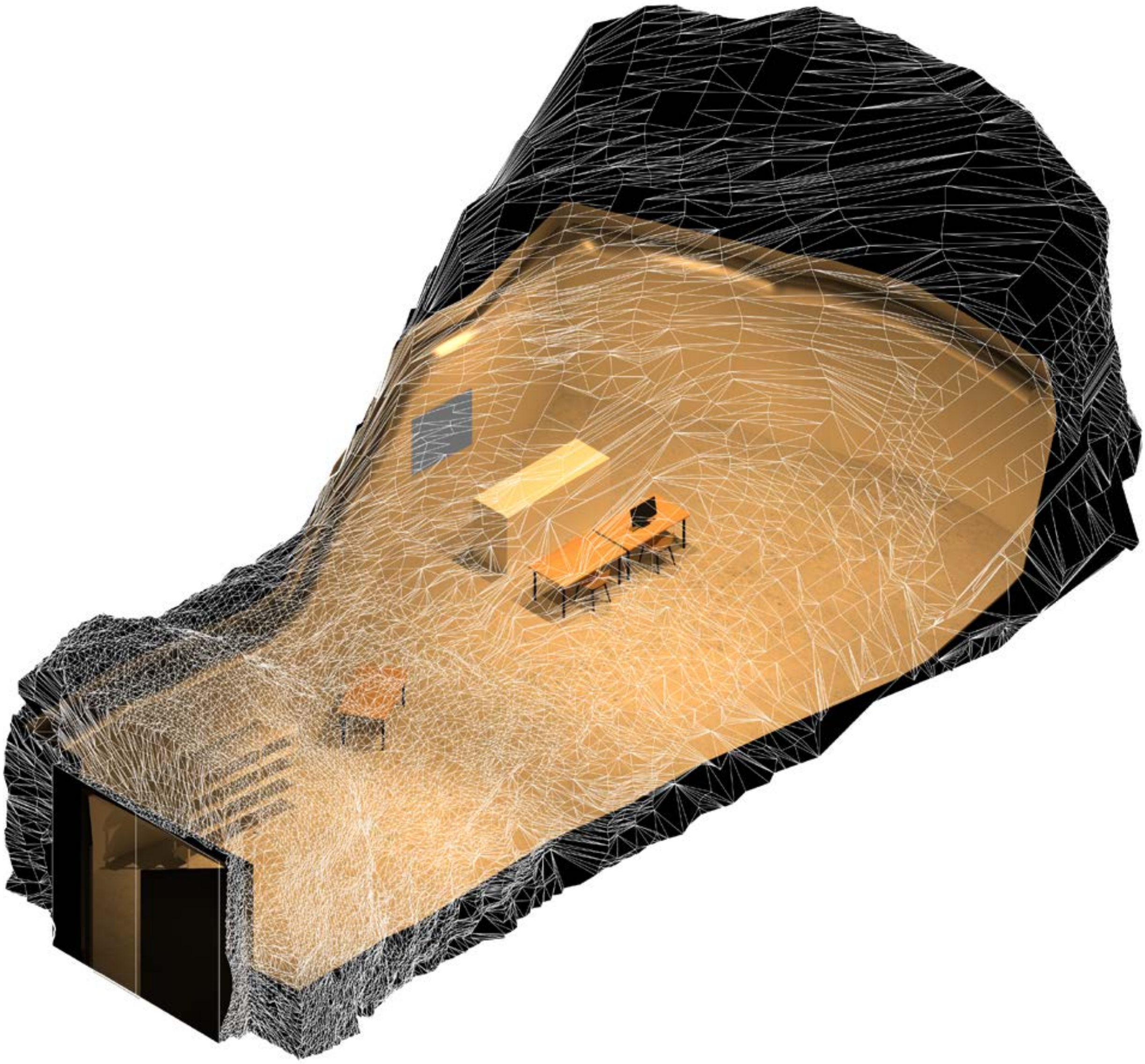


Fig. 45. Lab 2 isometric view

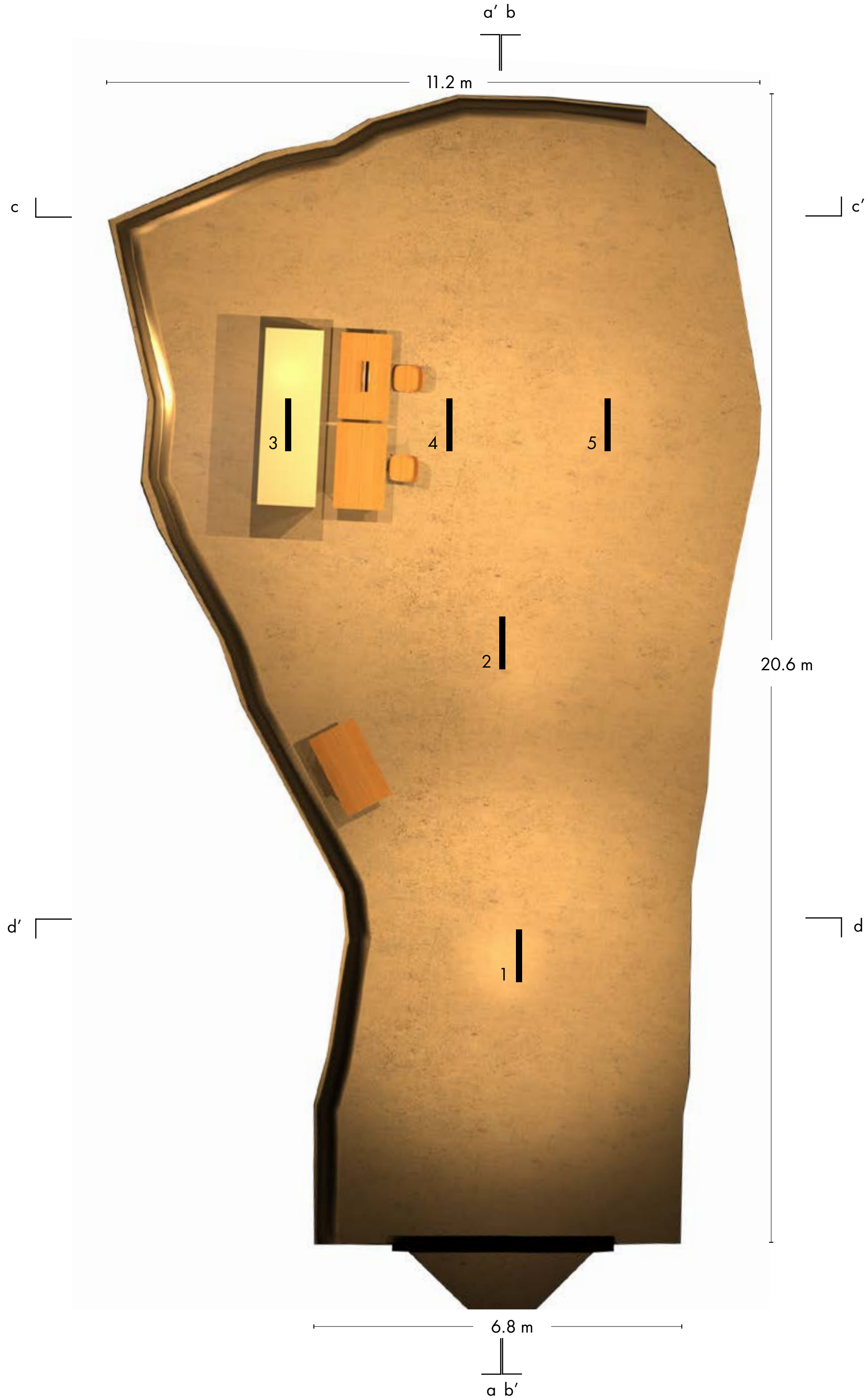
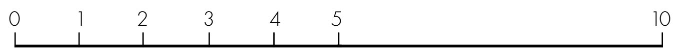


Fig. 46. Plan view of Lab 2



This plan view presents the current layout and lighting condition of Lab 2.
There are five downlights distributed in a T-shaped pattern in the space.

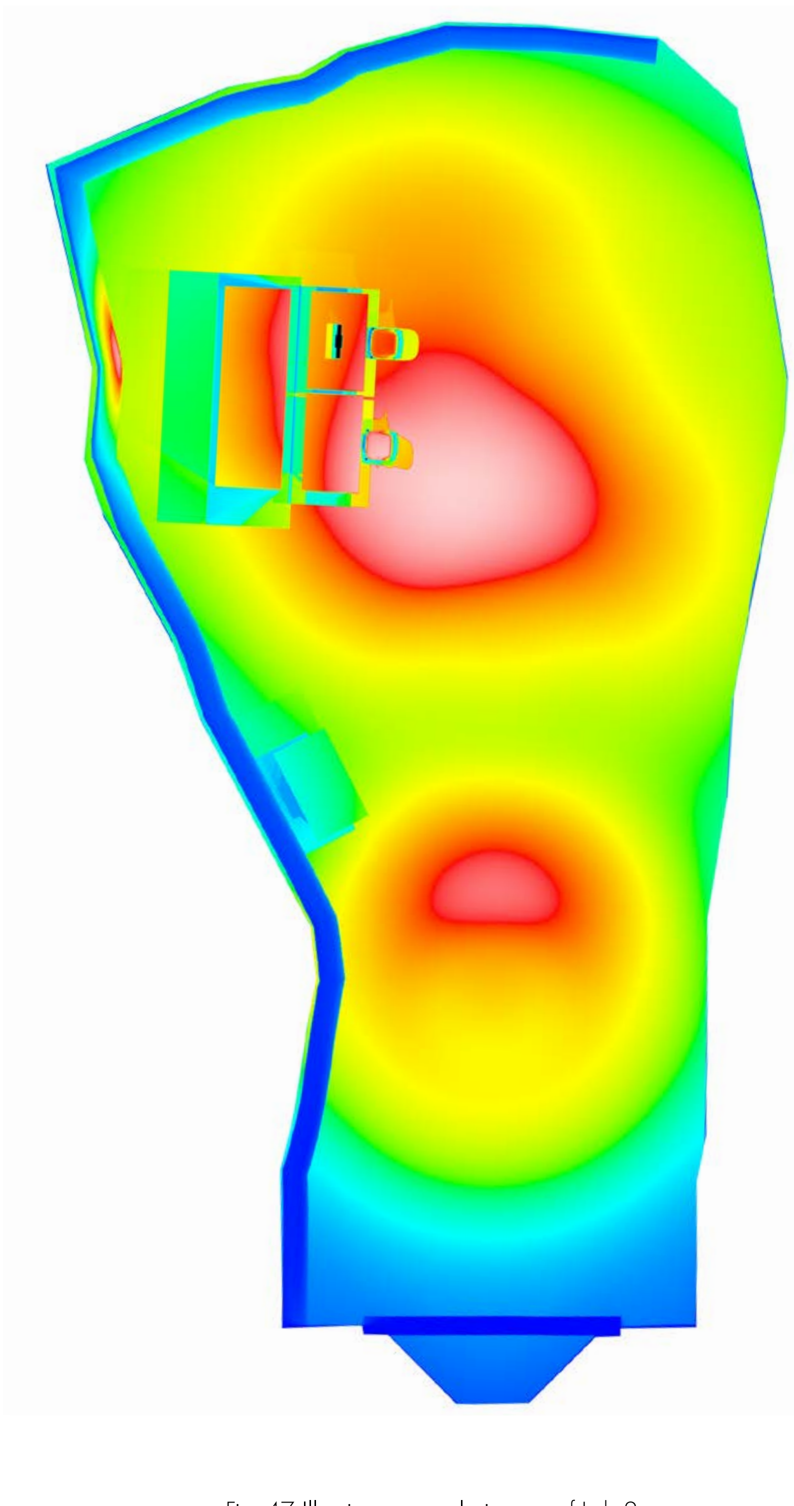


Fig. 47. Illuminance analysis map of Lab 2

lx 0 75 150 225 300

The highest illuminance levels are centred around two main points in the middle of the floor plan. No direct light is specifically directed to the walls.

3.4 Spatial and Lighting Analysis of Lab 2

3.4.1 Current condition of Lab 2

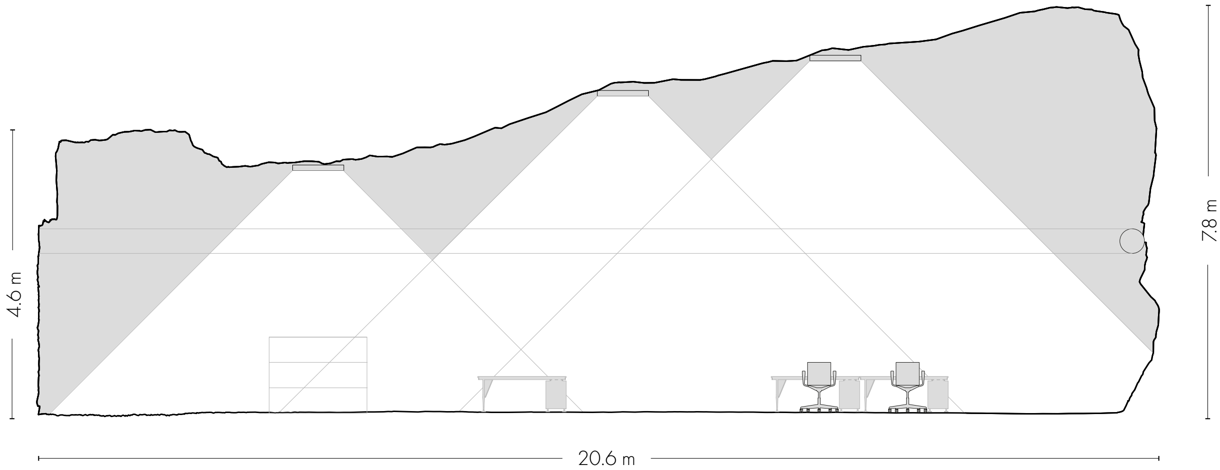
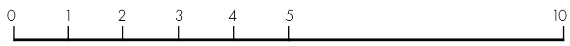


Fig. 48. a-a' section of Lab 2



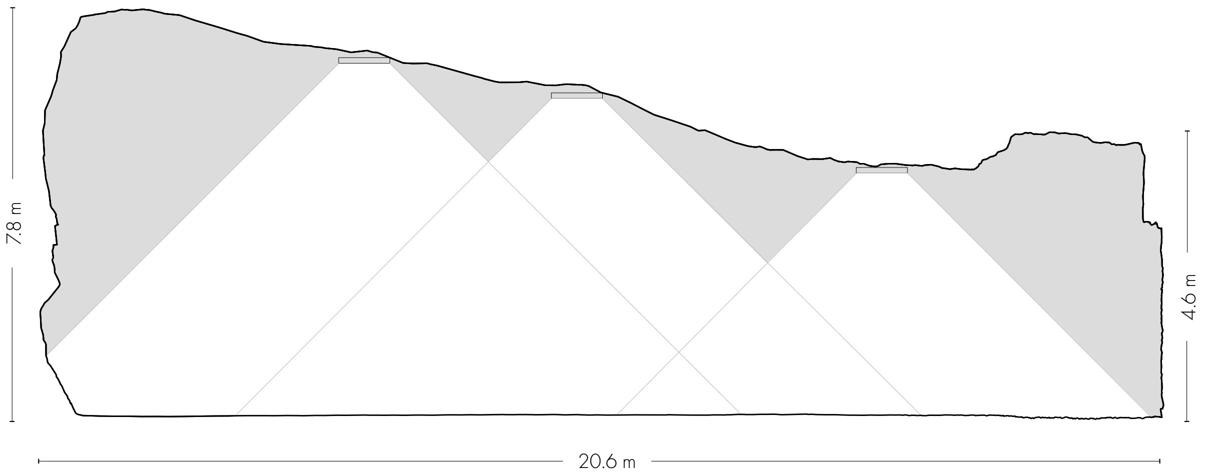


Fig. 49. b-b' section of Lab 2

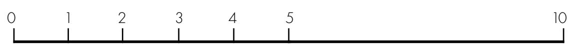


Fig. 50. Back wall of Lab 2.

CCTV camera installed in the ventilation duct. Dehumidifier and other electrical and internet cabling.

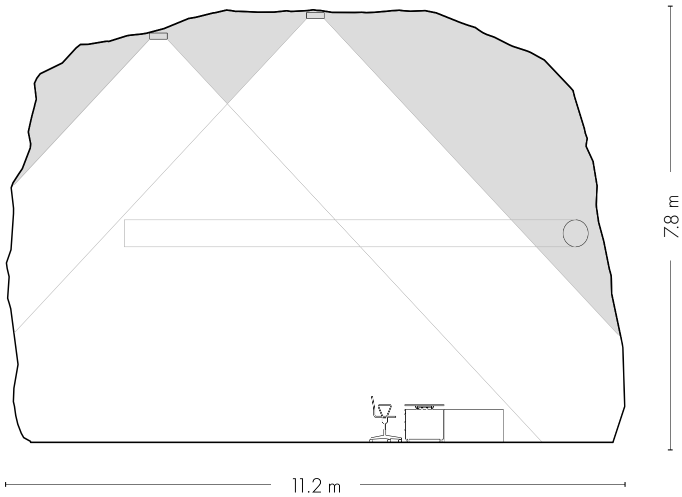
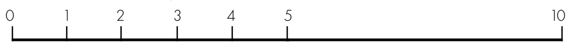


Fig. 51. c-c' section of Lab 2



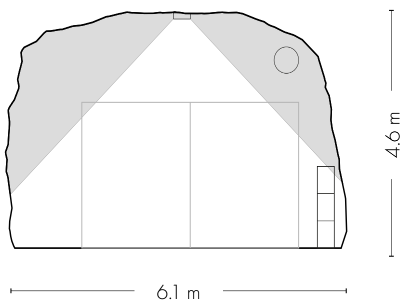


Fig. 52. d-d' section of Lab 2

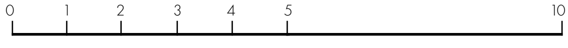


Fig. 53. Entrance of Lab 2.

3.5 Design Process of Lab 2

3.5.1 Study on plan

As of today, the existing space of Lab 2 offers 168 square metres of surface area and a ceiling height that ranges from 4 metres at the entrance to 7 metres near the back wall. The lighting is limited to five ceiling mounted luminaires distributed in a T-shaped pattern.

The new proposed layout intends to accommodate a variety of activities which may occur in an innovation laboratory. All furniture is foldable for added spatial flexibility. This is due to the fact that testing devices can take different shapes and forms. For that reason, the section of Lab 2 where the ceiling is at the highest point is reserved for experimentation devices. The partition wall is made of sound absorbing material and it is envisioned to become a vertical writing or visualisation surfaces.

Lighting works cohesively with all the other elements architecturally in order to create the light distribution and intensity that the space and user requires.

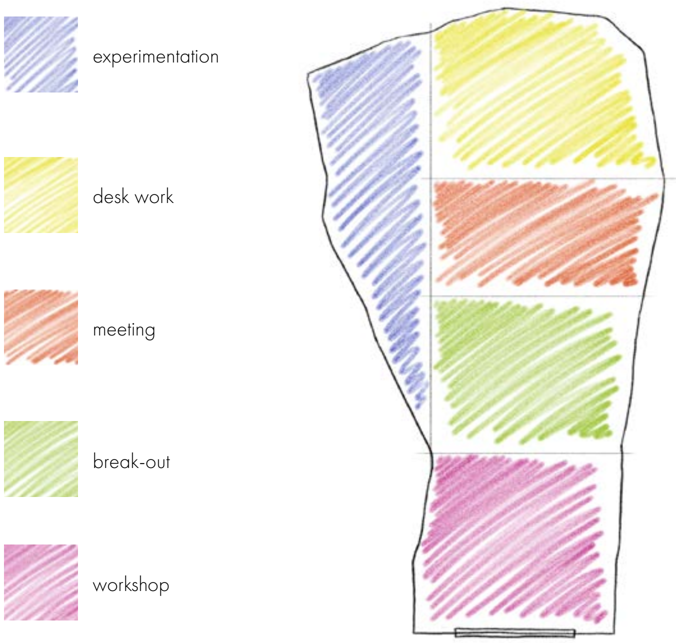
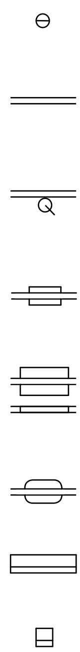


Fig. 54. Concept of spatial zones for Lab 2

Luminaire symbols used in the reflected ceiling plans.



1 in-ground wall washer

2 suspended track with integrated uplight

3 track-mounted directional spotlight with glare shield

4 track-mounted office luminaire

5 track-mounted pendant office luminaire

6 track-mounted projector

7 track-mounted uplight, asymmetrical

8 wall-mounted asymmetrical uplight

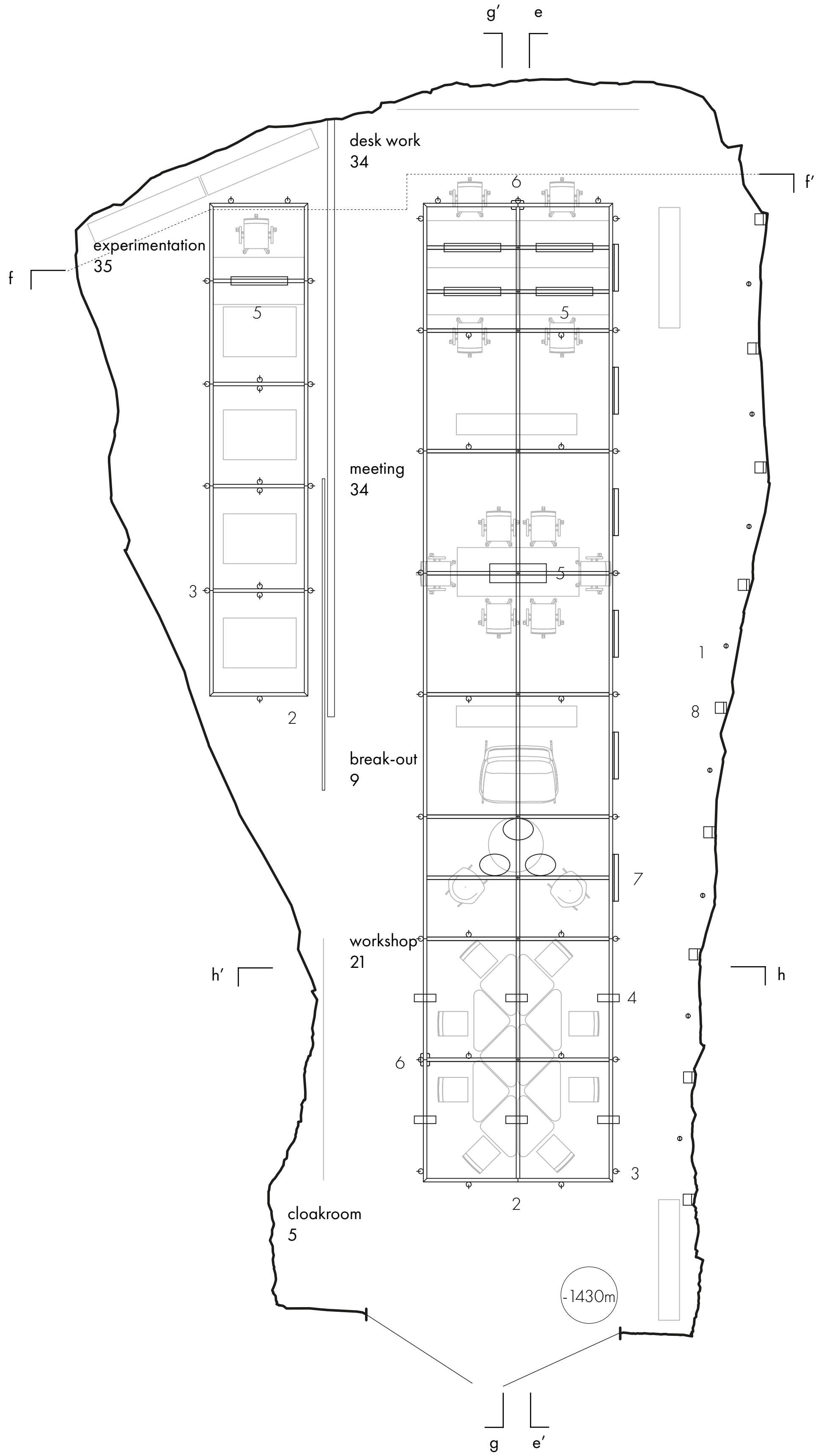


Fig. 55. Proposed reflected ceiling plan for Lab 2

3.5.2 Study on section

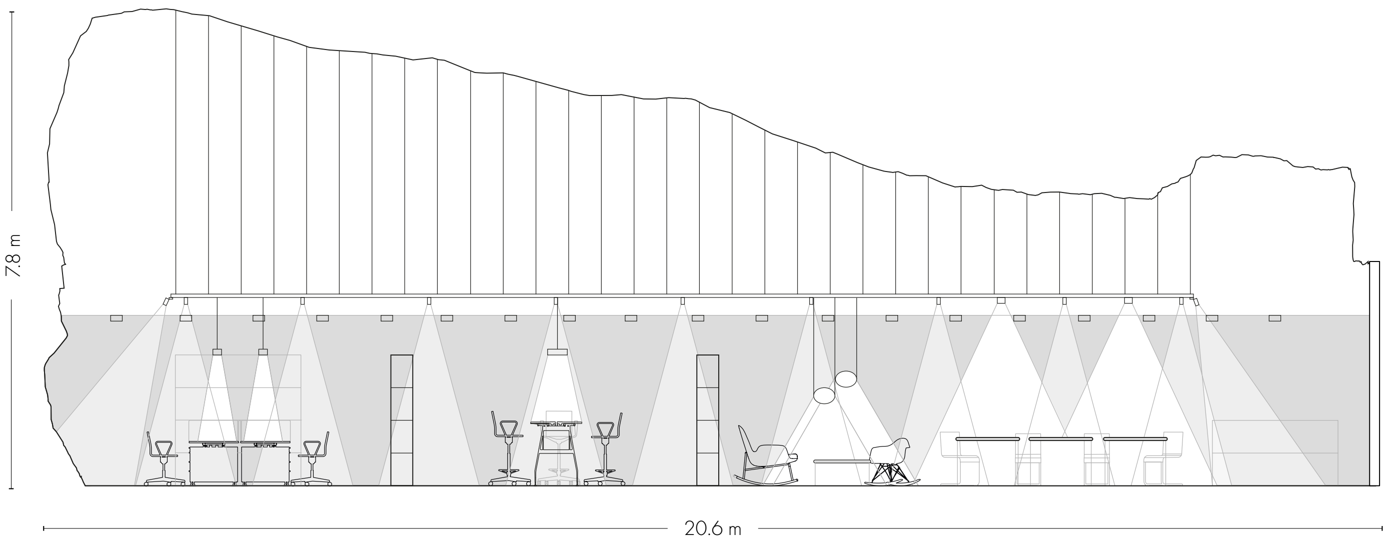
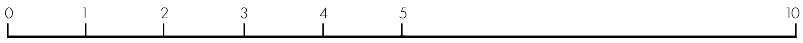


Fig. 56. e-e' section of Lab 2



The lighting track system suspended from the ceiling to a height of 2.8 metres from the floor level, combines the flexibility to install luminaires at any desired point with the visual comfort of the indirect light. The LED module is mounted flush on the top side of the track, projecting light onto the ceiling.

Uplights at 2.5 metres from the floor level also provide illumination onto the ceiling when there is need to emphasise this upper surface.

In-ground spotlights with glare shield along the perimeter of the wall project light upwards.

From left to right: The desk area is illuminated with lineal pendant luminaires optimised for office lighting. A rectangular pendant luminaire provides an evenly illuminated surface over the tabletop in the meeting area. Feature pendant luminaires offer direct lighting on the coffee tables in the lounge area. Finally, in-built spotlights emit wide beam light on the tabletops in the workshop area.

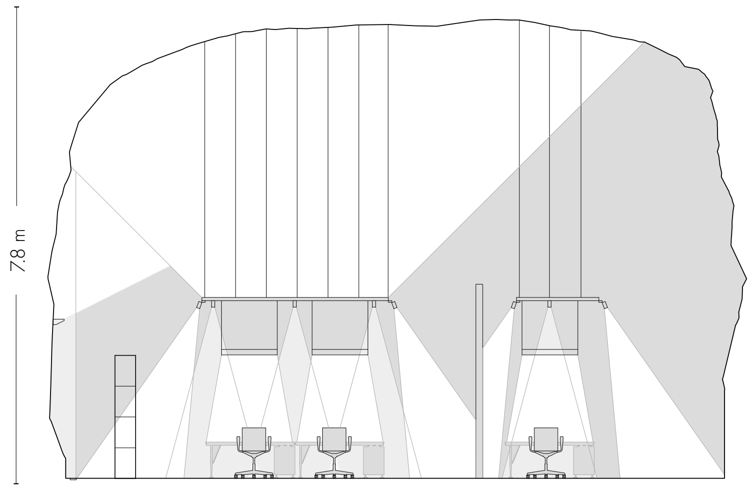


Fig. 57. f-f' section of Lab 2

From left to right: In-ground asymmetrical spotlights illuminate the wall on the left. Wall mounted asymmetrical luminaires emit light upwards accentuating the arched form of the ceiling. The lighting track system suspended through wires is used in both areas. Both desk areas are lit with oval wide flood and lineal pendant luminaires optimised for office lighting to provide visual comfort for desk work. However, the track in the experimentation area does not offer uplighting because it is not necessary and possibly detrimental when the testing devices need to be opened up. Spotlights with glare shield are used along the circulation area to increase floor illuminance.

The experimentation area on the right is divided from other areas by a moveable wall made of noise absorbing material.

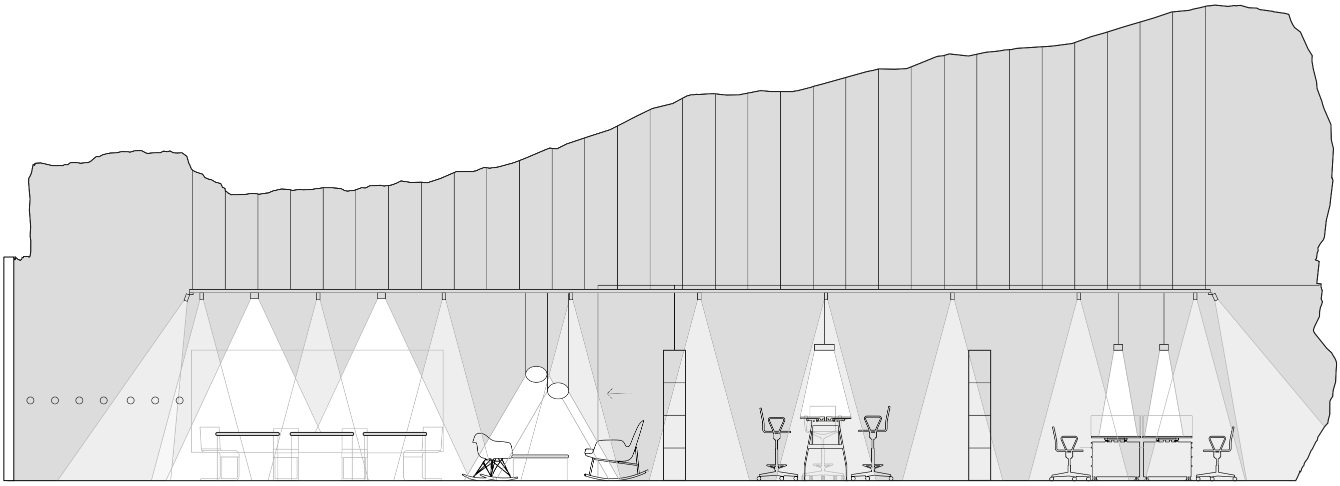
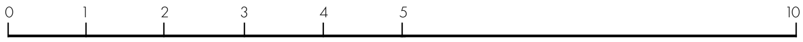


Fig. 58. g-g' section of Lab 2



From left to right: Spotlights with glare shield along the perimeter of the wall project light onto the floor to illuminate the circulation area. In-built spotlights optimised for office lighting emit wide beam light on the tabletops in the workshop area. Designer pendant luminaires offer direct lighting on the coffee tables in the lounge area. A rectangular pendant luminaire provides an evenly illuminated surface over the tabletop in the meeting area. The desk area is illuminated with oval wide flood and lineal pendant luminaires optimised for office lighting.

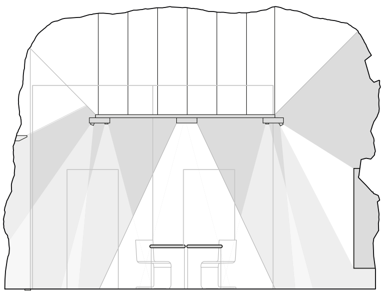
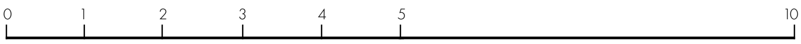


Fig. 59. h-h’ section of Lab 2



From left to right: In-ground asymmetrical spotlights illuminate the wall on the left. Wall mounted asymmetrical luminaires emit light upwards accentuating the arched form of the ceiling. The workshop area is illuminated with luminaires optimised for office lighting built in the lighting track system. The LED module in the lighting track system is mounted flush on the top side of the track, projecting light onto the ceiling and providing uniform indirect lighting to the entire area. Spotlights with glare shield are used along the circulation area to increase floor illuminance. Also, a projector has been built into the track system.

[92] L. Carroll, 'Alice's Adventures in Wonderland', McMillian & Company, London, 1865. p. 72-73.

" *Alice: Would you tell me, please, which way I ought to go from here?*

The Cheshire Cat: That depends a good deal on where you want to get to.

Alice: I don't much care where --.

The Cheshire Cat: Then it doesn't much matter which way you go.

Alice: --so long as I get SOMEWHERE.

The Cheshire Cat: Oh, you're sure to do that, if only you walk long enough. " [92]

CHAPTER 4 FINAL PROJECT

4.1 Scenarios for Retka

4.2 Scenarios for Lab 2

4.3 Lighting Design Themes

4.1 Scenarios

This section provides the rationale for the choice of luminaires in Retka restaurant and Lab 2 through a series of scenarios. To create scenario descriptions fundamentally involves one immersing oneself in the context of use.[93] Practically, a good scenario description shall enable the designer to envision solutions that respond to relevant actors, aims, actions, events, obstacles, contingencies, and outcomes.[94] In order to create significant scenario descriptions, a chart has been created. This chart offers a structure that ultimately helps to associate a description of each user's use of the space to lighting requirements.[95]

[93] J. Carol, 'Making Use: Scenario-Based Design of Human-Computer Interactions', Massachusetts Institute of Technology Press, Cambridge, Massachusetts, 2000. p. 259.

[94] Idem. p. 256.

[95] The scenario structure and scenario making chart in Table 16 and 17 have been adapted from the method used in the Lighting and Learning Scenario workshop tutored by Henrika Pihlajaniemi in the Spring term in 2019 which runs in parallel with the Well-lit research project.

Table 16. Detailed description of the scenario structure [95]

item	description
user	based on the list of users provided in the Callio 2050 vision, five user groups are created by role type.
time	time slots are representative of the time of the day: sunrise, morning, noon, afternoon, sunrise and night, in order to present how light supports the daily rhythm of the users in Retka and Lab 2.
activity	general activities that occur in activity-based workspaces.
experience and feeling	desired feelings and affections that the adaptive and intelligent lighting design of Retka hope to arise.
lighting mode	the permutations of directionality and distribution of a light source.
lighting intensity	static or dynamic changes in light intensity ranging from dim to bright.
lighting tone	subjective impressions of visually warm light may inforce feelings of pleasantness whereas cool temperature may stimulate visual clarity.
adaptation and intelligence	the comprehensive analysis of input data and transmition of luminaire parameters becomes possible through a wrist band, sensors, real time data analysis, pre-set programs and user interaction.

Table 17. Scenario-making chart [95]

TIME (11)	8 AM	9 AM
	1 PM	2 PM
	6 PM	
USER (5)	ADMINISTRATOR	BUSINESS
AREA (14)	FOOD SERVICE	LOCKER
	LOUNGE	BOOTH
	MEETING	BREAK
ACTIVITY (9)	ADMINISTRATIVE	BREAK
	EVALUATION	MEETING
EXPERIENCE (10)	CALMING	PLEASANT
	COMFORTABLE	HEALTHY
LIGHTING MODE (14)	DIRECT DOWNLIGHT	DIRECT UPLIGHT
	DIFFUSE DOWNLIGHT	DIFFUSE UPLIGHT
	LOCAL LIGHT	COVE LIGHT
LIGHT INTENSITY (9)	150 LX	250 LX
	DIMMING DOWN	BRIGHTENING UP
LIGHT TONE (9)	WARM	NEUTRAL
	NEUTRAL TO COOL	COOL TO NEUTRAL
ADAPTATION AND INTELLIGENCE (6)	MOTION SENSOR	PHYSIOLOGICAL ADAPTATION
	SOUND SENSOR	ANIMATION

10 PM	11 MM	12 PM
3 PM	4 PM	5 PM
MAINTENANCE	RESEARCHER	VISITOR
BAR	DINING	CAFÉ
COUCH	EXPERIMENTATION	DESK WORK
WORKSHOP	CLOAKROOM	
BRAINSTORMING	FOCUS/TECHNICAL WORK	REFLECTION
MEAL	LECTURE/SCREENING	
OPEN	CONNECTED	SOCIABLE
ENERGISING	INSPIRING	CONCENTRATION
DIRECT WALL WASHING	DIRECT UPLIGHT GRAZING	INTIMATE LIGHT
INDIRECT WALL WASHING	DIFFUSE UPLIGHT GRAZING	LUMINOUS OBJECT
PERSONAL LIGHT	BIDIRECTIONAL LIGHT	
500 LX	750 LX	1000 LX
LIGHT SHOWER	DIM PULSE	
COOL	WARM TO NEUTRAL	NEUTRAL TO WARM
COOL TO WARM	WARM TO COOL	
PSYCHOLOGICAL ADAPTATION	ASTRONOMICAL ADAPTATION	USER PROFILE SENSOR

4.1.1 Breakfast time in Retka

Callio maintenance and administration personnel start their working day by having breakfast at 8am in Retka. Before then, all personnel accessing the underground facilities must change their clothes to a work overall and wear a wrist band. This equipment is placed in the changing room lockers overground next to the lift.

All luminaires in Retka are dimmed to 20% of their total intensity throughout the day and brighten up when sensors detect users approaching. General lighting is provided mainly by the light structures built in the light track system which project light upwards onto the ceiling, filling the entire space with indirect light. For an open and spacious effect, the in-ground luminaires located opposite to the entrance warm up and brighten up simulating the colour temperature of the sunrise light. Many users feel inspired by the wall washing effect of this feature wall. Some employees turn to the smart lockers where they may leave their personal belongings (books, tablets, toiletries, wallets, etc.) before heading to the food counter. These lockers have been equipped with an intelligent lighting system that senses the wrist band of the user and opens the door automatically, the chosen locker brightens up inside so that the user can see well what is in it.

Each user learns more about his or her nutritional needs during the work day when he or she reaches the buffet counter. The intelligent system built in the wrist band collects and tracks physiological data from the user. The result is that some areas of the buffet counter receive a more intense and direct spotlighting to indicate to the user that he or she should eat certain foods.

It is time to find a comfortable seat in the dining tables. The sensors built under these tables detect the presence of the user and the downlights start to brighten up as a narrow spot. Users can simply enjoy their customised meal silently or chat to other colleagues or watch the wide screen if they wish. Whenever they like they can tap on the wrist band how they are feeling today or even record a voice message that can be sent via wireless network to the service desk about their experience in the space.

The system sends updates about occupancy rates and mood status to all users. The service desk manages any issues related to light, temperature, noise, air or any other matter that concerns users. When it is time to start their work routine, they get up from their seats. This triggers the table downlights to automatically dim down. They leave their tray in the washing up space.

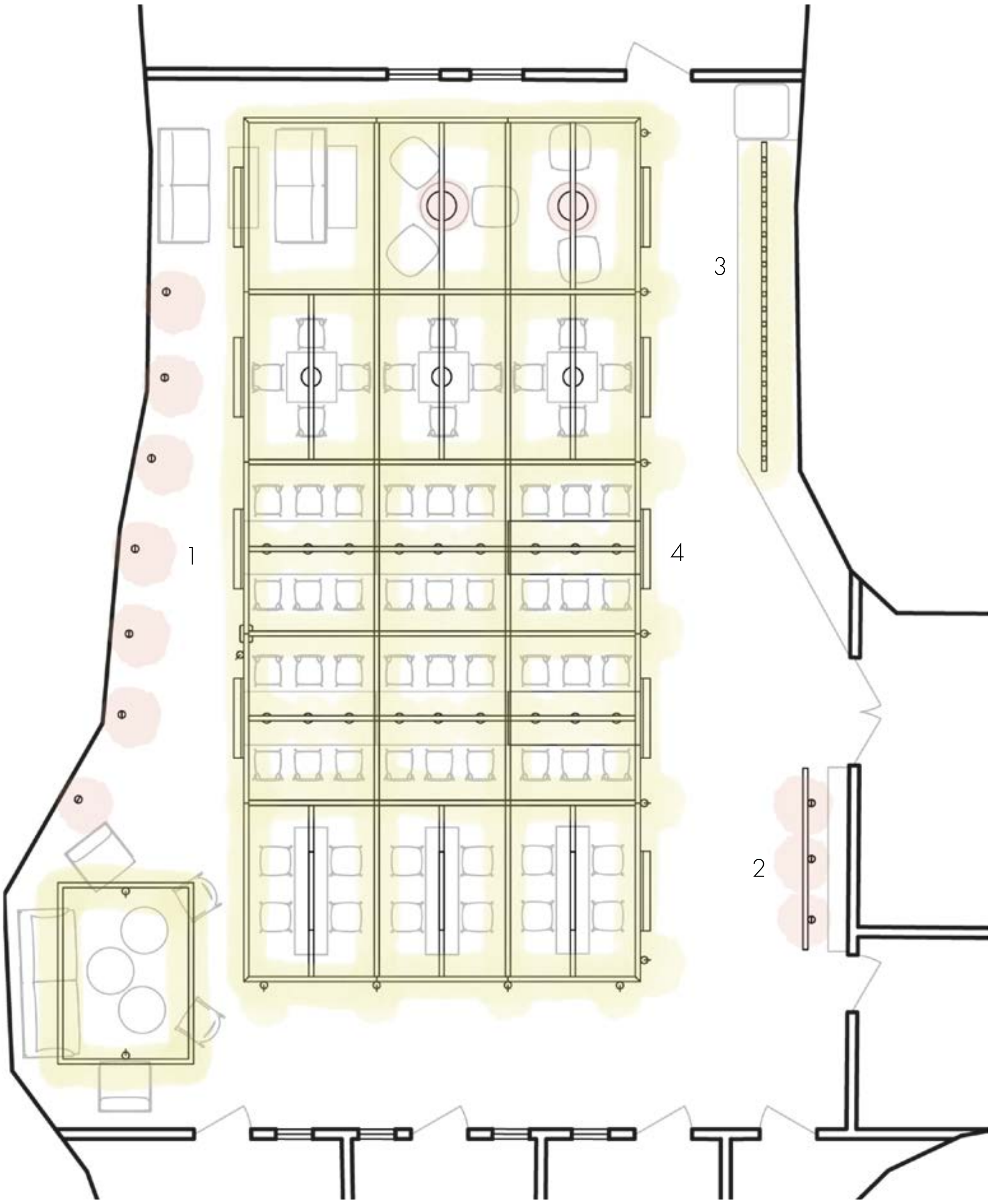


Fig. 60. Sketch of lighting plan for scenario 1 in Retka

1	in-ground wall washers simulate sunrise light	-	**tunable white in-ground wall wash**
2	lights brighten when employees approach lockers	-	**asymmetric downlight with motion sensor**
3	food counter lights brighten up linked to physiological data	-	**downlights with light intensity changes**
4	dining tables lights brighten up when employee sits down	-	**narrow spotlight with motion sensor**

Fig. 61. Light study of the breakfast time in Retka

Fig. 62. Visualisation of the breakfast time in Retka

4.1.2 Coffee break at Retka

Business people and researchers usually start their work day at 10am. It also coincides with the administrators’ coffee break. As was the case with maintenance and administration personnel, business people and researchers must wear a wrist band if they wish to access the facilities. These two user types may work seasonally underground.

An animation of thick clouds welcomes them in Retka which causes the general colour temperature of the space turn to neutral. This mid morning animation relates to the real time weather change in Pyhäjarvi which has been detected by the system. The group that arrives feels as if the morning light filled the room entirely. This is quite an unexpected feeling to have because they are aware that they have travelled one and a half kilometres underground and yet, they feel connected to the outdoors because of the simulation of the morning blue sky cool and bright light. To the excitement of many in the room, a very interesting animation is projected on the upper ceiling: a time lapse of the passing of clouds on the morning sky. The atmosphere in the room is quite inspirational.

There are laptops in the lockers in the event they would like to borrow one to do some work in Retka while they are enjoying a cup of coffee. One hovers the wrist band in front of the locker and a door opens. The space inside the locker is backlit so one can perfectly see the inside. The door is pushed back in and a slim light frames the empty locker to indicate that the laptop has been lent but sooner dims down.

The business people take a seat on the couch. The sensors detect the presence of those users which triggers the spotlights built in the track system to brighten up in a neutral tone. This turns the area into a space to concentrate as they work on their laptops. The researchers gather around the tall tables. They began to brainstorm about one project. The spotlights brighten up in a neutral tone. The table tops are nicely lit. This is a sociable atmosphere. In the meanwhile, the two administrators sit in the lounge area. The pendant lamps have been programmed to turn warmer. So, within minutes it feels as if a ray of light had been filtered through the cloudy animation and shined on the lounge area.

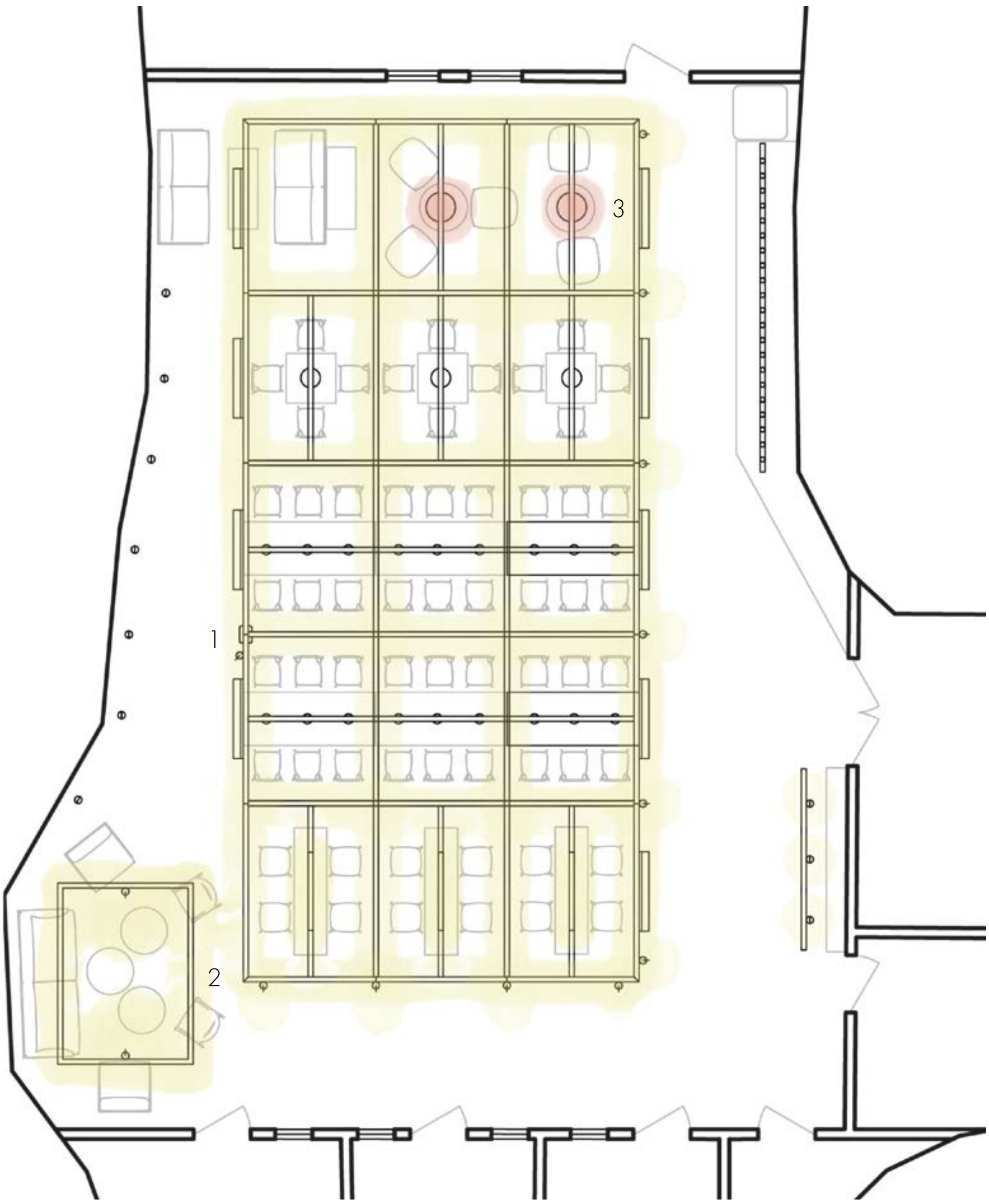


Fig. 63. Sketch of lighting plan for scenario 2 in Retka

1	cloud animation projected on the ceiling -	light projection of weather data
2	spotlights in the couch area lit up on approach -	spotlights with motion sensor
3	pendant lights in the lounge area change to warmer -	tunable white personal lighting

Fig. 64. Light study of the coffee break in Retka

Fig. 65. Visualisation of the coffee break in Retka

4.1.3 Lunch time at Retka

The dining tables are reserved for lunch only. This means that the lights only operate when the sensor detects those users who have first scanned their wrist band in the food counter before seating on the dining table. It is midday and the sky has turned clear on a late winter day so the uplights are dynamically changing from the previous cloudy overcast sky tone of round about 4000 K to clear sky tone of 6500 K. The overall light intensity is starting to also increase rhythmically to render a pleasant atmosphere.

The system has analysed data from the calorie consumption of the maintenance users. During the morning maintenance-type users performed some heavy physical work. When they arrive at the buffet counter the juice bar brighten up first. The sensor scans the wrist band for the nutritional profile information of the user and the spotlights integrated in the buffet hood brighten up in accordance to each user's recommended diet. It is intended that the user will feel inclined to select recommended foods that suit his or her daily calorie consumption and support his or her custom diet.

The detectors under the dining tables send information to the pendant downlights built in the tracking system to brighten up the moment they take a seat. It appears that the World Rally Championship is being broadcast on the wide screen. Within minutes the atmosphere is dimmer to provide for concentration on the wide screen.

It is nearly the end of the lunch break, all lights become brighter to indicate that it is time to resume work. They rush to squeeze in a quick cup of coffee for an added energy boost. The system analyses the restorative levels of all the users after the lunch break while they are still in Retka. It concludes that the maintenance-type users should be energised for one last time. While they are on their seats a brighter cooler downlight beams over the table surface. They feel fresh as if they had just had a shower, literally. They send very positive feedback for such comforting experience by tapping on the screen of their wrist band.

Eventually they all leave their trays in the washing up space and walk towards the exit door. The dining table lights are automatically turned low to minimum energy consumption. The same energy saving program is activated for the food counter and circulation areas. The hot plates in the food counter are almost empty and needs cleaning. The system sends an update to the kitchen staff. The lights brighten up on approach of the waiter and remain at a high intensity so that he or she can inspect the hot plates and to wipe the surfaces if necessary.

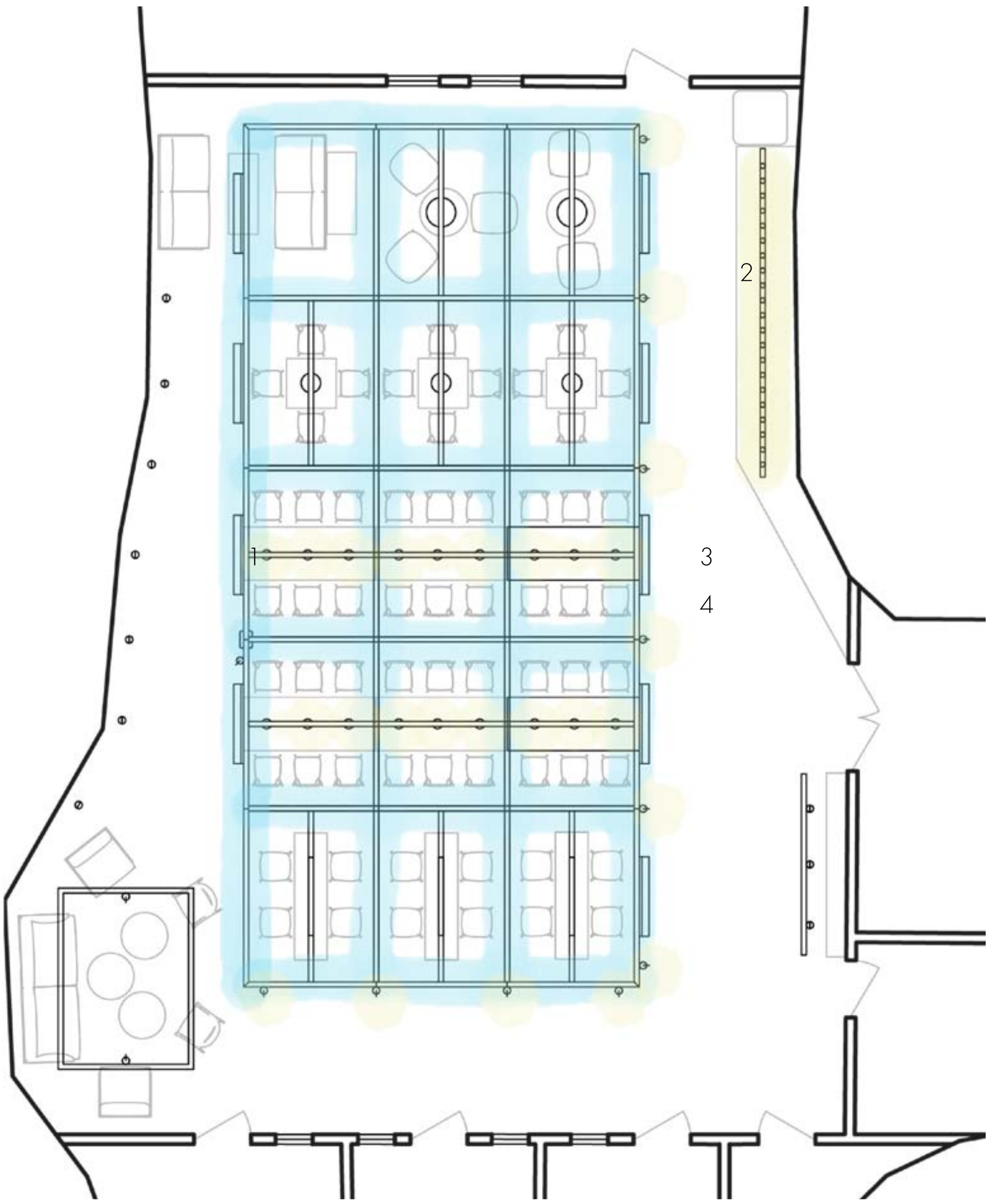


Fig. 66. Sketch of lighting plan for scenario 3 in Retka

1	uplights simulate the weather change in Pyhäjarvi	-	tunable white uplights in track system
2	spotlights in food station hood brighten up	-	spotlights with light intensity changes
3	pendant lights dim down due to broadcast	-	narrow spotlights with sound sensor
4	pendant lights brighten up linked to physiological data	-	tunable white downlights

Fig. 67. Light study of lunch time in Retka

Fig. 68. Visualisation of lunch time in Retka

4.1.4 Callio Open Day in Retka

There is an important event occurring at two o'clock in the afternoon. Several visitors are attending the Callio Open Day and their first stop is Retka. The kitchen and cleaning personnel are busy preparing the room for a large amount of attendees. The uplights built in the tracking system emit bright and neutral light to help them see all surfaces in great detail. In the meantime, the administrators are welcoming the group of visitors at surface level. Visitors are led to the changing rooms to find a fitting pair of boots and wear a wrist band to access the underground facilities at Callio. Business people and researchers are beginning to enter Retka. A quite intense general light has already started to turn lower after the cleaning crew notified the system that the job was done.

For a large number of visitors, it is their first time in a deep underground workspace. Any negative changes of their physiological state will be detected by the sensors in the wrist band and flagged to the service desk. But for lesser acute issues, the system will automatically adapt the lighting conditions to improve the physiological state of the user. A few visitors feel stressed about the lift journey. The system orders the luminaires in the hallway to render a warmer colour temperature to help them feel comfortable in such unfamiliar setting.

A video about Callio's past, present and future is playing in the big screen so the remaining lights are dimmed down. Only the uplights shine a soft and neutral light to the upper ceiling in order for the visitor to look up and open their field of vision. The luminaires in the area of the food counter begin to brighten up to show that there are hot and cold drinks and snacks for the attendees.

Before they are taken around the main level for a tour on foot, they must fill in an evaluation form which has been printed on paper located on the tall tables. The intensity of the spotlights increase to accommodate the visual task. The luminaires in the bar counter begin to dim down when the sensors detects than no one has stopped by for a couple of minutes. As it is time to begin the tour, the motion sensor detects everyone has left the room so the lights are turned down to energy saving mode.

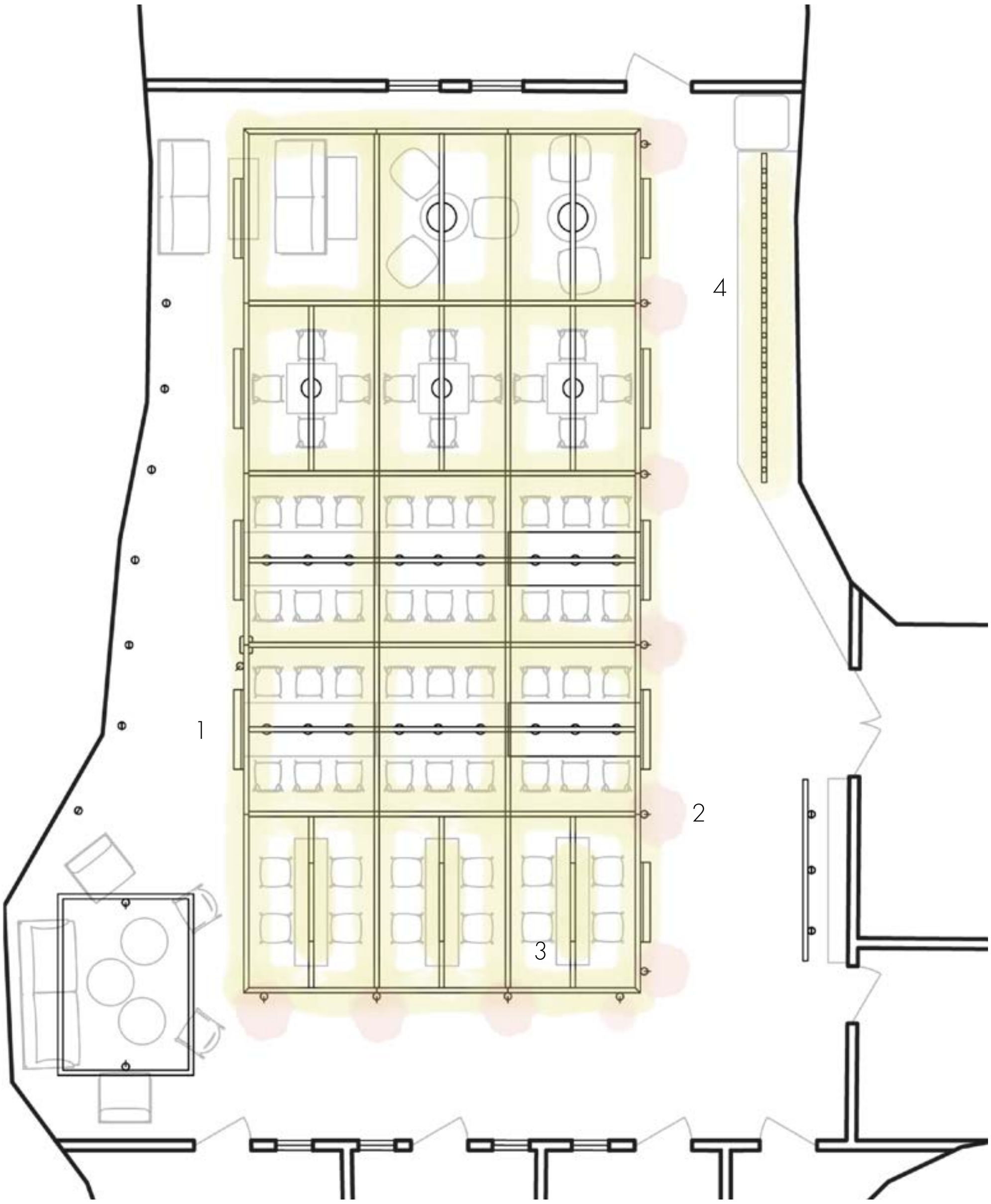


Fig. 69. Sketch of lighting plan for scenario 4 in Retka

1	uplights lit up linked to cleaning task	-	**uplights in track system with pre-set programme**
2	spotlights along corridor warm up link to physiological data	-	**spotlights adapt colour temperature to physiological data**
3	pendant luminaires above tall tables brighten up	-	**pendant luminaires with pre-set programme**
4	light structure point lights sources dim down	-	**point lights with motion sensor**

Fig. 70. Light study of Callio Open Day at Retka

Fig. 71. Visualisation of Callio Open Day at Retka

4.1.5 Social event in Retka

Retka has been booked for the evening for a social event. The lighting atmosphere plays with the combination of indirect and cool light and warm accent lighting as well as some lighting animations are being projected in the space and coordinated with the rhythm of music. The projector installed in the tracking system emits a lighting animation upwards that creates a fun and inspiring atmosphere. The disk jokey for the night has got at his disposal a lighting desk which is linked to the luminaires so that she can mix music and lighting altogether.

This is a great opportunity for the visitors to meet and greet the personnel at Callio. The theme of the event is "drinking light" which has proven to be a quite popular event. Glasses become a luminous object where to pour the drink. The effect that this sensory art piece intends to achieve is that people establish a more direct contact with light through the feeling that they are drinking light. This experience can prove to be unique to each individual but some report that they feel energised.

Two business people return to the room because one visitor has left her mobile phone behind. They tap in their wrist band that the search task requires medium light intensity and it has to be in the areas around the food counter. The system detects the device before the people had and shines an intense spotlight onto the lounge chair. The mobile phone is collected and brought back to its owner.

Fig. 72. Sketch of lighting plan for scenario 5 in Retka

1	accent lighting for added dramatic effect	-	tunable white pendant luminaires
2	music artist uses a lighting desk to mix light hue and music	-	light hue changes
3	drinks become lumious objects	-	luminous objects
4	a lost phone is found thanks to the bright luminaries	-	narrow spotlight with user interaction

Fig. 73. Light study of social event in Retka

Fig. 74. Visualisation of social event in Retka

4.1.6 Cleaning at Lab 2

The cleaning crew has been called in to tidy up Lab 2 at 9am. The cleaner checks in by hovering the wrist band over the first door leading to storage space before the Lab 2. The cleaner walks towards the Lab 2 entrance now. Few metres closer, the sensor detects his proximity and the Lab 2 door opens automatically. When the Lab 2 is not in use general lighting is kept at 20% of its total light intensity to save energy. The system has been notified of the cleaning job so the cleaning pre-set program is activated which consists of all downlights to brighten up so that surfaces can be completely visible. The intelligent sensors built in the cleaning robots take the floor space whereas the cleaner focuses on surfaces higher off the ground, such as tables and shelves.

The lounge area has pendant lights that brighten up to a neutral tone on cleaner's approach. After dusting off the coffee table, the cleaner feels like he has some spare time before the next job, so sitting down on the lounge chair seems like a good idea. He taps into his wrist band that he wants to take a 10 minutes break. The atmosphere renders itself warmer into a calming scene. The pendant lights over the table dim down to almost crepuscular light levels. The uplights that were illuminating the ceiling also dim down and a beautiful lighting animation starts to play. Cleaning robots receive an order from the system via wireless to go on stand by mode. The cleaner find himself very relaxed then. When 10 minutes have passed, the atmosphere becomes brighter and the colour temperature turns to cooler. The resting cleaner feels very much energised after this light effect and resumes the job. The downlights in the remaining areas brighten up in the same fashion as the lounge area on when the cleaning gets closer to dust off the surfaces and dim down when he moves on to the next. In a matter of minutes the cleaning job has been completed. The cleaner notifies the system that he is finished by tapping on his wrist band.

A reminder pops up on his wrist band to urge him to change the filter inside the air duct. The system has been built in with air quality sensors in each area of the room. He can read a summary of results on his wrist band screen. He duly changes the filter and the system re-runs a scan to update the air quality graph. He is finally done with the job and the Lab 2 door latch gets automatically released. Lab 2 lights dim down to energy saving mode upon his leaving.

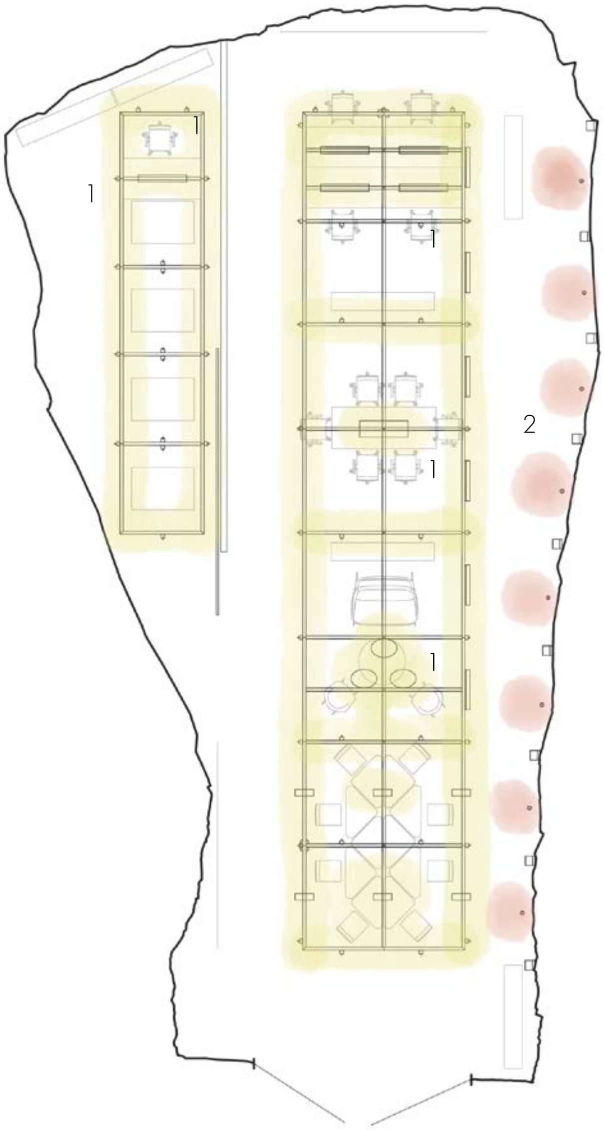


Fig. 75. Sketch of lighting plan for scenario 1 in Lab 2

1	pendant luminaires brighten up to pre-set programme	-	**pendant luminaires with pre-set programme**
2	colour temperature and intensity changes for a variety of atmospheres	-	**tunable white and intensity change in-ground wall washer**

Fig. 76. Light study of cleaning in Lab 2

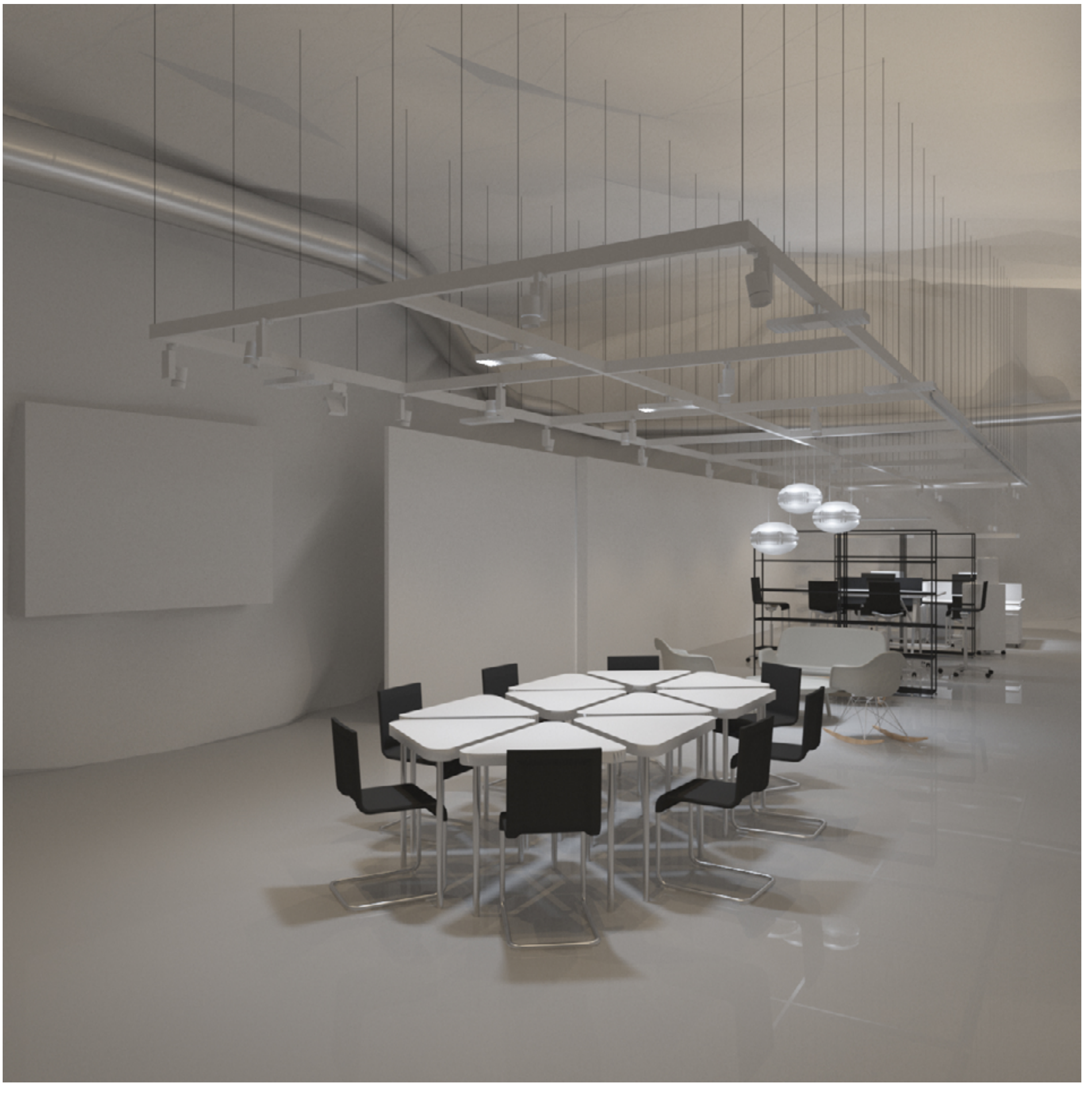


Fig. 77. Visualisation of cleaning in Lab 2

4.1.7 Productive morning in Lab 2

A group of researchers have just reached Lab 2. Some go directly to the experimentation area to check on the progress being made. Physics testing devices can be noisy so the dividing wall is made of sound absorbing material. The desk placed in this area has been illuminated with a pendant downlight for which the user can tune to his or her liking using the control board installed on the top right hand corner of the table.

Another four researchers set up in the quiet desk area at the back of Lab 2. They aim to do some evaluation report of their latest finding. They quite enjoy the atmosphere in this area because they can easily concentrate on the task. To help them do so, they are pendant lights directly above the desks and a control board on each desk. Some report to prefer neutral colour temperatures but others concentrate better with a cool tone. The lighting levels are pleasant enough for them to write or scribble on paper as well as focus their glaze on their computers. The smart board is backlit in a neutral tone. The board is often used to project graphs and presentations so the backlit effect brings it to the fore as a luminous object in itself.

The remaining group of researchers take the workshop area to begin a brainstorming session on some findings from reading into a topic in physics. As a first meeting, they are meeting to share some key ideas through some slideshow and debate extensively. The best way to begin is by having a light breakfast and coffee on the table. In order to not feel in a very formal atmosphere, the wall washers brighten up to soft neutral tone illuminating the walls. While the wide flood downlights right above the workshop table brighten up softly in warm to create a seamless open atmosphere in the area. When it is time to begin the brainstorming session, one of the researchers choose a preset from the controller near the smart board that would be suit the activity. This preset turns off the wall wash uplights and brightens up the back of the smart board which emphasises the luminous object by creating a halo effect around it.

As lunchtime approaches, the researchers in the experimentation and quiet desk areas prepare to go to Retka. The spotlights in line with the corridor brighten up to lead them to the entrance of Lab 2 when the sensor detects movement while the areas they move away from dim down to energy saving mode. Before leaving they collect the equipment they left stored in the cloak area. The brainstorming session continues on and perhaps will end just before the other researcher return from lunch.

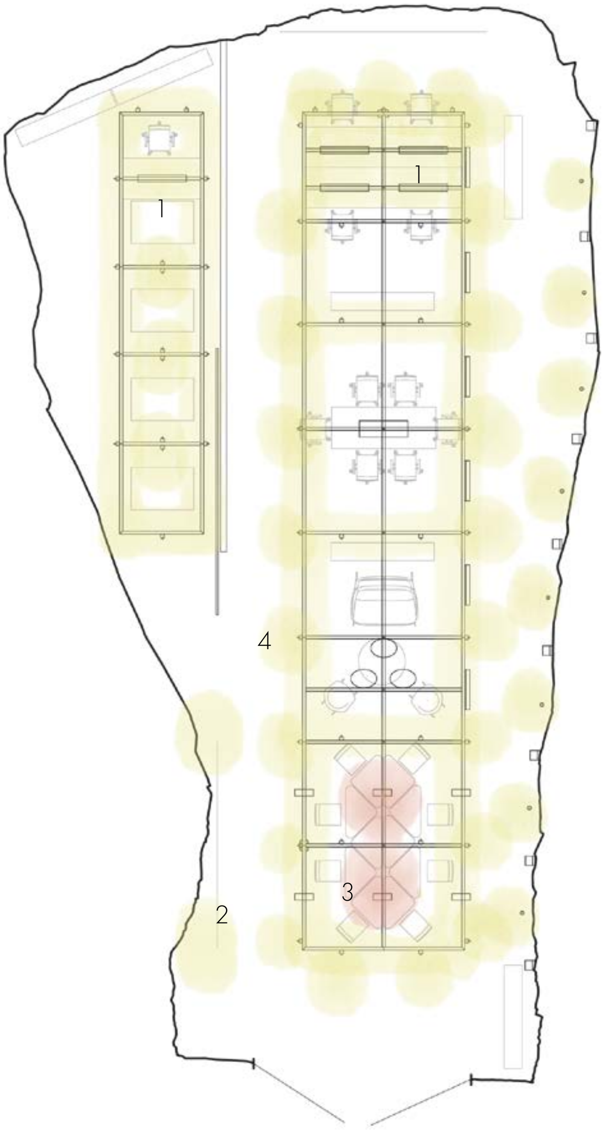


Fig. 78. Sketch of lighting plan for scenario 2 in Lab 2

1	lineal and direct office lighting with control board	-	**tunable white and light intensity to user preference**
2	bakclit luminous screen	-	**accent lighting**
3	warmer office work dowlights in workshop area	-	**tunable white downlights optimised for office work**
4	spotlights along the corridor brighten up	-	**spotlights with motion sensors**

Fig. 79. Light study of productive morning in Lab 2

Fig. 80. Visualisation of productive morning in Lab 2

4.1.8 Business meeting at Lab 2

It is nearly 1pm and the brainstorming session is almost about to end. The hospitality service has been notified that lunch has to be served at Lab 2 after the brainstorming session. When the session ends, one of the participants change the lighting setting to breaktime using the controller. The downlights right above dim down and turn warmer to create a more pleasant atmosphere in preparation to the arrival of the food. The in-ground luminaires turn on to illuminate the rough texture of the rockwall which has an effect over the overall space by enlarging it. Some participants have moved to the meeting table where they can stretch their legs while they have their lunch and also because they like to explore other the space during this informal planned meeting. The pendant lights above the meeting table brighten up to a soft intensity and warm tone to render a calming atmosphere. The hospitality service is called in to collect the lunch dishes and serve coffee.

A couple of business people turn up in Lab 2 for coffee. They had contacted the organiser of the brainstorming session previously to ask whether they could join in just to bounce off some business ideas with the participants. The organiser messaged back in the morning to say it was fine to meet at coffee time. The hospitality service notifies the system that the job is done and the system re-sets the lighting attributes to open meeting in the meeting and workshop areas. All direct downlights dim down slowly and are replaced by medium intensity and neutral tone uplighting in order to illuminate the ceiling and wall rough textures. This is quite an inspiring atmosphere to be in, while having coffee and chatting to different people.

One business person uses the light controller in the workshop area to adjust lighting to the slideshow he is to share on the big screen about the latest project he has been working on. The wide screen brightens up and the intense backlit does too in order to draw the attention of the participants. The uplights dim down to a very soft intensity so that it will not be too distracting. The wall washers change to a warmer tone to create a more pleasant atmosphere during the short presentation. When the question time begins the audience can tap on his or her wrist band that they would like to ask a question and the system register the order of questions. The presenter accepts the first question and a dim spotlight shines over the person who will be speaking. When she stops, the noise sensor detects no voice and the dim spotlight turns off gradually after a while.

Their time in the Lab 2 is coming to a close. As they leave the space, the motion sensor scans for people in Lab 2. No one is in it so all luminaires turn off to energy saving mode.

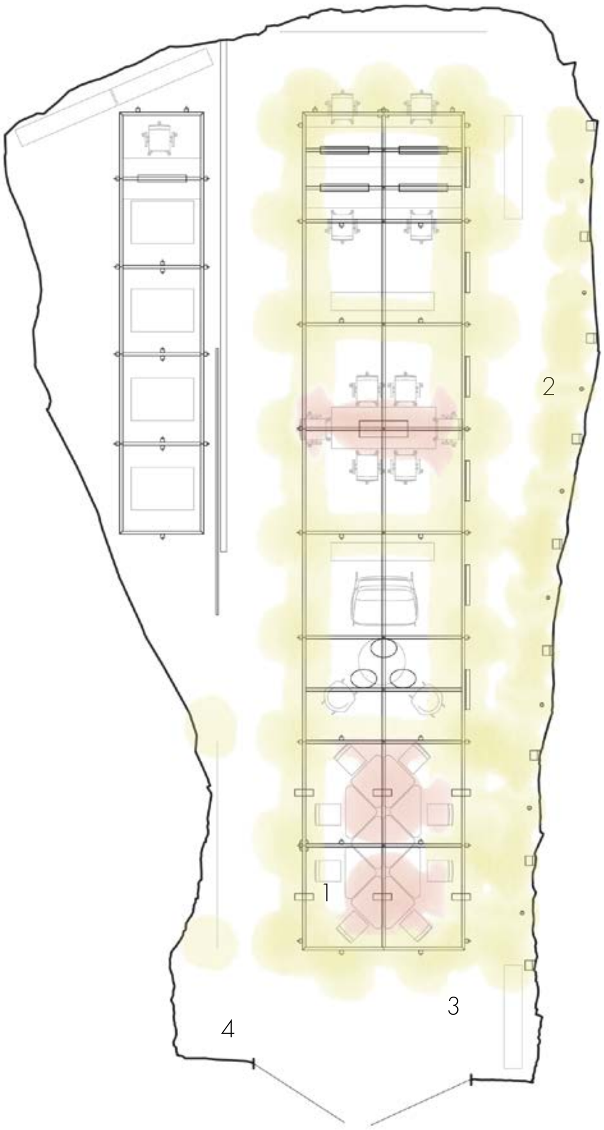


Fig. 81. Sketch of lighting plan for scenario 3 in Lab 2

1	downlights dim down and turn warmer	-	**tunable white downlights with light intensity changes**
2	in-ground wall washers brighten up	-	**wall washers with light intensity changes**
3	downlights brighten up and turn neutral	-	**tunable white downlights with light intensity changes**
4	downlights dim down as slideshow begins	-	**downlights with light intensity changes**

Fig. 82. Light study of business meeting in Lab 2

Fig. 83. Visualisation of business meeting in Lab 2

4.1.9 Callio Open Day in Lab 2

Lab 2 is about the host an open day to visitors. Researchers will take the opportunity to show the facility and explain how they conduct research in this deep underground testing hall and working space. As the door opens visitors see the wall washers shimmer as if the luminaires were prepared to brighten up. This atmosphere creates mystery to the visitors. Ever so slowly the uplights on the wall begin to brighten up and change from cool to neutral. The ceiling is beautifully illuminated, revealing the length of the space and its arched form. There is enough ambient light to be able to appreciate the dimensions of Lab 2. One of the researchers happily voice to all "welcome to Lab 2, an odd but awesome space, just like the stuff we do in here!". Everyone bursts out laughing. The noise sensor detects the levels of noise are high so the luminaires brighten up slightly since it is programmed to adapt light intensity to level of publicness. The atmosphere turns quite sociable.

The first area they move to is the experimentation area. Visitors are only allowed to watch the experimentation area from the sliding door. After the experimentation area, they move to the desk area where they will be shown a full presentation on the current experiments in Lab 2. The organiser selects the light pre-set for concentration which is usually the programme the researchers use when they work in this area. The visitors can see the intensity of the downlights have increased and it has changed to fairly neutral so they can imagine what a day at work must feel like. As the video starts playing on the wide screen, the pendant luminaires over the desk dim down. The visitors attention is drawn to the wide screen which feels like it was suspended thanks to the backlighting feature. The backlight intensifies if the audio is louder and dims a little if the noise is softer.

The corridor spotlights brighten up to indicate the way out. The space must be vacated now before 5pm because a team of researchers must use the space then. The motion sensor scans for people after the door has been shut and turns all luminaires down to energy saving mode.

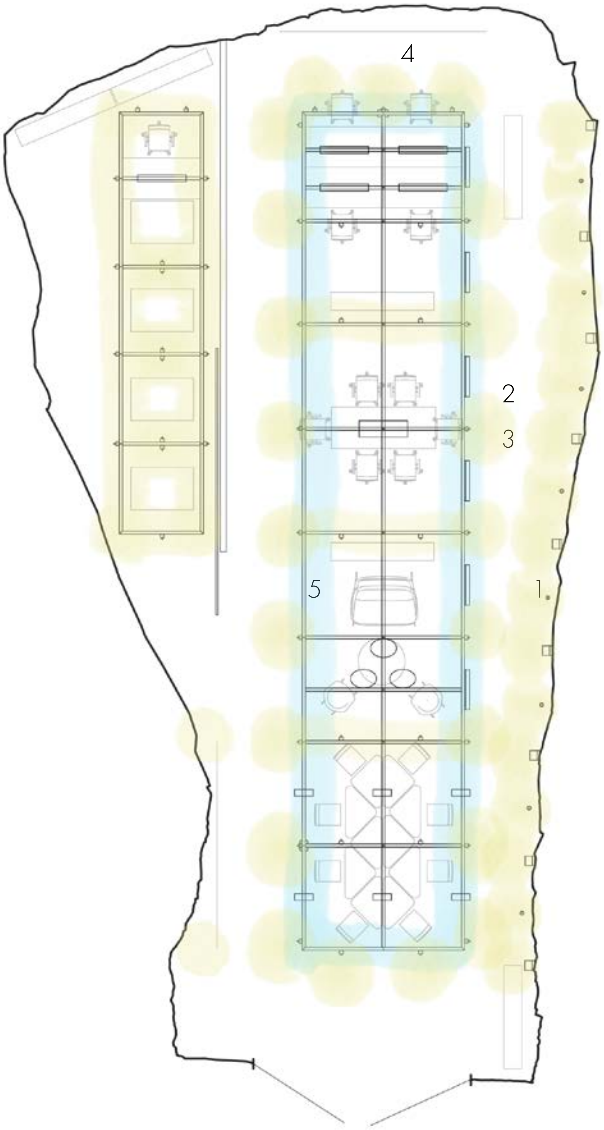


Fig. 84. Sketch of lighting plan for scenario 4 in Lab 2

1	in-ground wall washers brighten up	-	**in-ground wall washers with light intensity changes**
2	wall recessed uplights turn to neutral	-	**tunable white uplights**
3	general lighting becomes brighter due to the noise increase	-	**uplights with noise sensors**
4	lights dim down when video projection	-	**uplights and downlights with pre-set programme**
5	spotlights along corridor brighten up	-	**spotlights with motion sensors**

Fig. 85. Light study of Callio Open Day in Lab 2

Fig. 86. Visualisation of Callio Open Day in Lab 2

4.1.10 Eureka in Lab 2

A team of researchers have been working against the clock to deliver the results of their latest experiment. Most of them are terribly exhausted. The system has been tracking their physiological condition and flagged up that their resting time was not enough to cover for the peak of activity in the last days. Therefore, the system has automatically overwritten the pre-set lighting programme for highly technical work at 5pm which usually turns the luminaires to a warmer tone to simulate the approaching time for sunset. Instead, the luminaires turn to higher intensity and a cooler tone to stimulate concentration. Additionally, the wall washers brighten up on time has if casting a light shower on the rockwall. The researchers report to feel more energised than before they entered Lab 2.

One can feel a deafening silence in the room, the submission deadline is approaching. The testing device has just produced the latest report and gets suddenly displayed on the wide screen. This report will either validate the research question which could possibly shake the world of modern physics. The researchers cannot believe what they are seeing in front of their eyes. The results perfectly validate their hypothesis. The lights behind the wide screen begin to flash in this special moment. The system has prepared a hologram to explain the experimentation process which is projected right above the desks so that the researcher can evaluate the importance of the discovery. All luminaires become quite dim to give more presence to the hologram.

The breakthrough must be announced to the media. One administrator in charge of marketing and communications is invited to join the room remotely. Her face shows up on the wide screen as the downlights above the desks brighten up and the wall washers turn on too. The administrator can perfectly see who is in Lab 2. After the report has been completed, the researchers are ready to leave the space with a very satisfying feeling. The spotlights along the corridor guide them to the door. The motion sensor runs a scan over the entire room before shutting off all luminaires to energy saving mode.

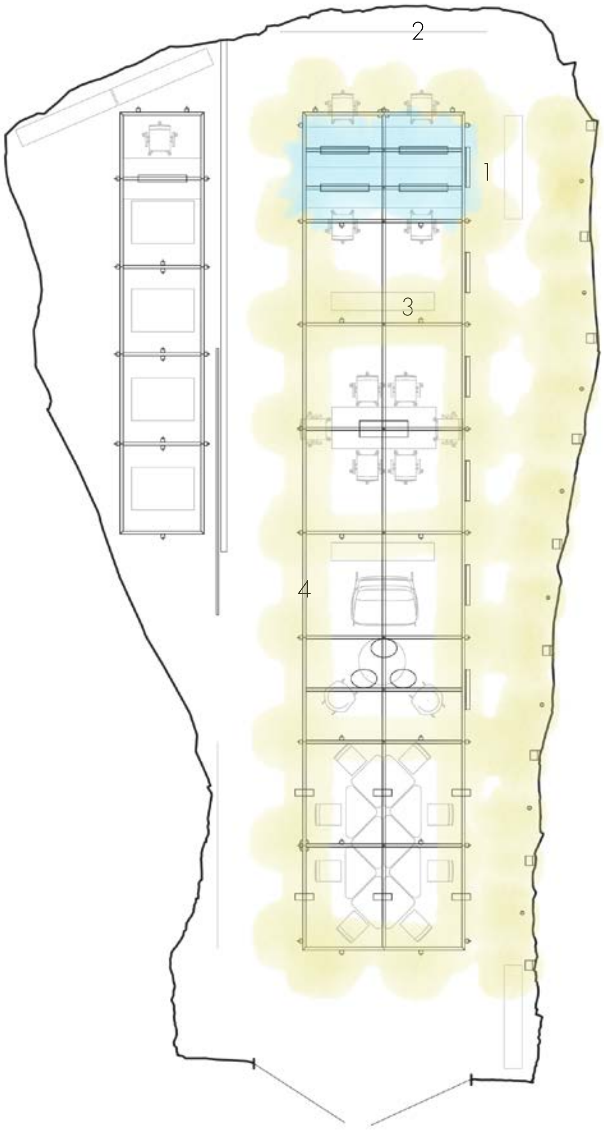


Fig. 87. Sketch of lighting plan for scenario 5 in Lab 2

1	pendants brighten up and turn to cool	-	**physiological data changes intensity and tone**
2	backlit luminous object	-	**accent lighting**
3	general lighting dim down when presentation	-	**light intensity changes to uplights**
4	spotlights dim down when researcher leave the room	-	**spotlights with motion sensors**

Fig. 88. Light study of eureka moment in Lab 2

Fig. 89. Visualisation of eureka moment in Lab 2

4.2 Lighting Design Themes

4.2.1 Circadian Rhythm

The indirect or reflected lighting from the vertical surfaces such as walls offers visual comfort while increasing general light intensity. Therefore, it increases visibility and decreases the chance of glare. Additionally, the direction of the reflected light on vertical surfaces affects our perception of the space and our biological clock or wake-sleep rhythm, i.e. circadian rhythm.

In line with the above-mentioned, the vertical surfaces in the scenarios are illuminated following certain dynamism both in height, colour temperature and light intensity. Ultimately, it is mimicking the rhythmic pattern of natural daylight. From a user perspective, the perceived dynamic change in lighting may decrease negative feelings experienced in spaces with nil exposure to natural light. In effect, the perceived dynamic changes in height, colour temperature and intensity of natural daylight are brought indoors by designing with luminaires that not only direct light towards the different sections of the vertical surfaces, but are also equipped with tunable white and light intensity intelligent adaptation.

For a morning light effect, walls are illuminated along the base just as when the sun rises over the horizon. The colour temperature at this time of the day is gradually changing from warm to neutral so the tunable white luminaire emits warm to neutral light too. The light intensity increases over time.

Just as the sun keeps rising in the sky, uplight luminaires built in the tracking system brighten up while the base of the wall becomes dimmer. This dynamic change in height is also coupled with the change of colour temperature, from neutral to cool.

At midday, the sun reaches full height in the sky. Walls and arched ceiling are illuminated intensely thanks to the uplights and wall washers. The colour temperature is set to cool and the light intensity is at its brightest.

In the early afternoon, the sun begins its descend. The wall washers brighten the wall surface softly while the colour temperature starts to change from cool to neutral while the uplights start to dim down.

At sunset, the sun is hovering over the horizon. The wall washes begin to dim down in warm colour.

However, one of the most important features of the intelligent and adaptive lighting in this project is that users are able to overwrite any pre-set programme. In the scenarios, I introduce the concept of light shower which casts cool and bright light onto the user if she or he would like to feel re-energised. On another occasion, the system itself overwrites the pre-set programme as it has collected negative results from the physiological data of the users.

Table 18. Design Theme: Circadian Rhythm

sun height	height	colour temperature	vertical surface light intensity
sunrise	wallwash-up	warm to neutral	250 lx dim
morning	wall wash	neutral to cool	250 lx 500 lx brighten up
noon	suspended-up	6500 k cool	500 lx bright
afternoon	wallwash-down	cool to neutral	500 lx 250 lx dim down
sunset	wallwash-up	neutral to warm	250 lx dim

Fig. 90. Light study of ‘Breakfast time at Retka’ scene

Fig. 91. Light study of ‘Lunch break at Retka’ scene

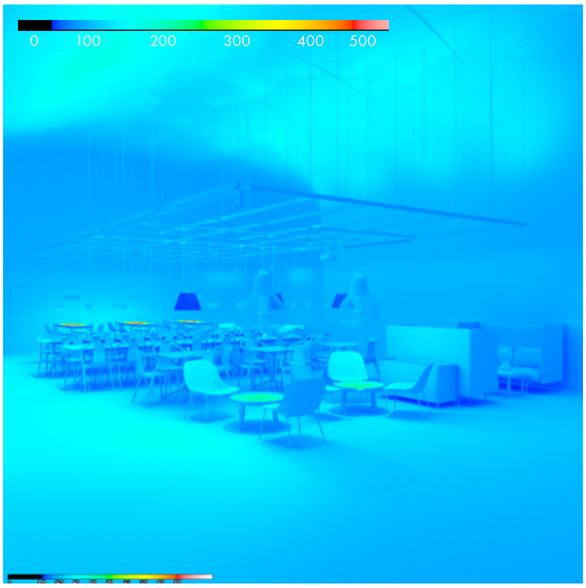


Fig. 92. Light intensity of ‘Coffee break at Retka’ scene

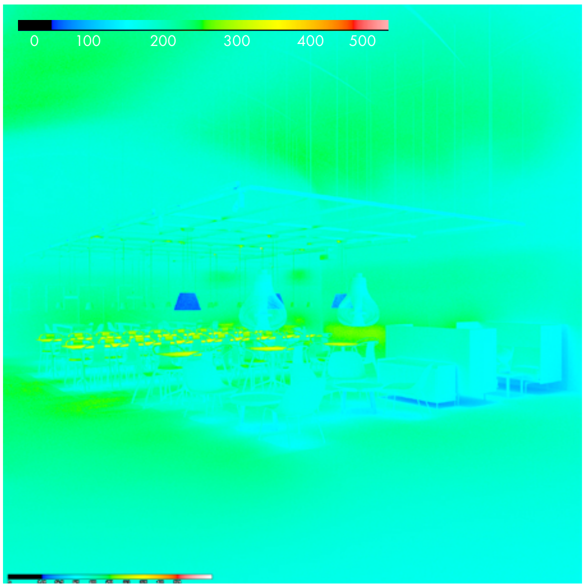


Fig. 93. Light intensity of ‘Lunch break at Retka’ scene

The early morning scene in Retka is purposefully lit to a warm colour temperature over the tables while the light intensity is around 250 lux on the walls.

At lunchtime, Retka welcomes people with a cooler colour temperature overall while floor and ceiling are illuminated evenly to around 500 lux for a fresh and spacious atmosphere.

Fig. 94. Light study of 'Cleaning in Lab 2' scene

Fig. 95. Light study of 'Business meeting in Lab 2' scene

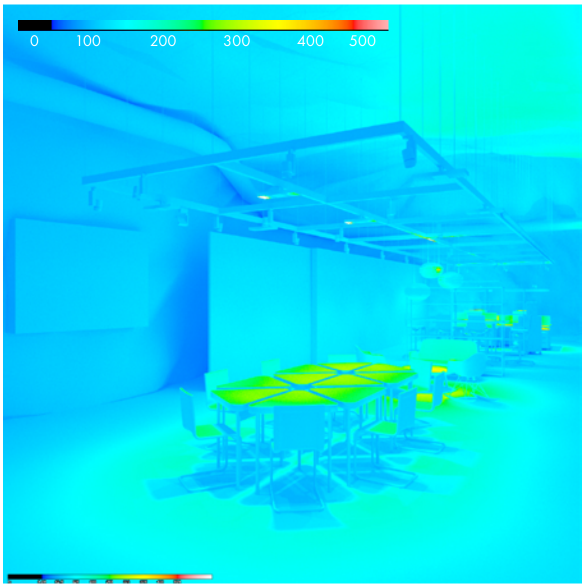


Fig. 96. Light intensity of 'Cleaning in Lab 2' scene

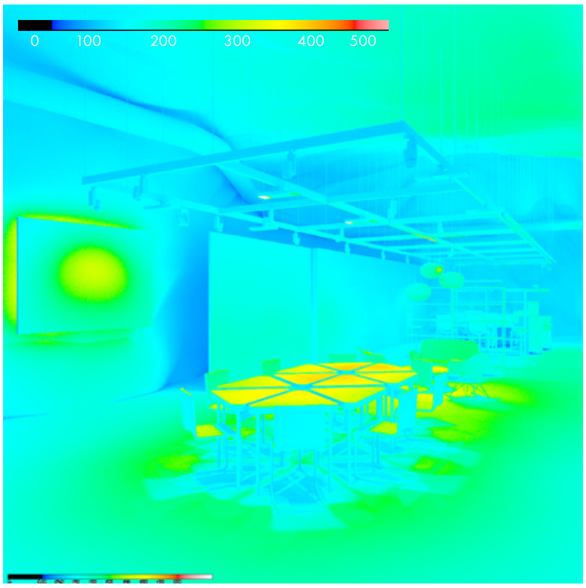


Fig. 97. Light intensity of 'Business meeting in Lab 2' scene

The late morning scene in Lab 2 is rendered to a neutral colour temperature on walls and the light intensity is just above 250 lux while the ceiling begins to brighten up.

As the afternoon approaches Lab 2 lighting turns warmer and dimmer. Walls are lit just over 300 lux.

4.2.2 Activity

With lighting, designers can create adequate atmospheres for the visual and non-visual requirements of specific activities. In contrast with the previous circadian rhythm design theme, here we focus on the illumination of horizontal planes. A horizontal plane is a flat surface at a right angle to a plumb line, such as a tabletop or floor. The majority of activities are performed seated and therefore users require a tabletop surface where to write, read, type on a keyboard or eat, among other activities.

The table on the right hand side illustrates the standard light levels for each nine activities. However, light intensity and colour temperature values can always be altered by the user. For instance, in the event of tiredness, the user can increase the light intensity and turn the colour temperature to cooler in order to feel re-energised.

Table 19. Design Theme: Activity

Fig. 98. Administrative

500 lx / neutral

Fig. 99. Brainstorming

250 lx / warm

Fig. 100. Break

250 lx / warm

Fig. 101. Evaluation

750 lx / neutral

Fig. 102. Lecture

250 lx / neutral

Fig. 103. Meal

250 lx / warm

Fig. 104. Meeting

250 lx / neutral

Fig. 105. Reflection

250 lx / warm

Fig. 106. Technical work

500 lx / neutral

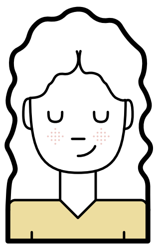
4.2.3 Interaction

The interaction between the end user and the lighting system as described in the design themes of circadian rhythm and activity can be understood as implicit. The system processes the external data, such time of day or weather forecast, and user actions as input data and triggers lighting adaptation.

However, throughout the scenarios I also explored explicit interaction between the end user and the lighting system. I introduced wrist band as a lighting control mechanism that is used to collect physiological data of the user in real time and for the user to overwrite lighting pre-set programmes. On another occasion, I described how lighting control boards can be manipulated by users to change the lighting setting to fit their lighting preference.

As a design idea, the user could explicitly interact with the lighting system through the digital interface on the right hand side. It consists of a dashboard that collects personal data of the user and through which feedback can be sent to the service desk. The pair of adjectives I propose are adjectives I have used myself in devising the scenarios when considering how users would experience light and space. The system would log the specific location and time for which the entry has been made. I envision that there would be an artificial intelligent that would process the data and create new lines of command to the luminaires to respond accordingly.

VISITOR



ABOUT

Anna is a 25-year old student from Oulu, Finland. Anna has just completed her bachelor's degree in Geoscience. In the autumn she will begin her master's degree in sustainable mining. It was the first time she has ever been visiting a mine. She would recommend visiting.

HEALTH

Anna wakes up at seven in the morning everyday and she sleeps eight quality hours. She considers herself a morning type.
Anna leads a very active and healthy lifestyle.

SPACE

Calmness / Safety

Stressful	Calming
Indifferent	Enthusiastic
Unpleasant	Pleasant
Unprotected	Protected
Insecure	Secure
Unsafe	Safe

Confinement

Confined	Open
Suffocating	Airy
Isolating	Connected
Lonely	Sociable

Affection

Scary	Comfortable
Harmful	Healthy
Boring	Lively
Dull	Inspiring
Distracting	Focus easily

LIGHT

Visual Performance

Dim	Bright
Uniform	Directed
Contrast	No contrast

Visual Comfort

Glare	No Glare
Hard Light	Soft Light
Flicker	No Flicker

Attractiveness

Pleasant Light	Unpleasant
White Balance	Hue
Static	Dynamic

Location

Retka restaurant (Dining area)

Time

09:30 AM on Tuesday 27 May 2019

FEEDBACK

Write here...

4.2.4 Energy consumption

Generally speaking, the efficient and effective use of lighting is associated with energy and cost savings. Sustainability is one of the most important aspects in design and it certainly is the case in lighting design. At present, all luminaires operate 24-hours a day, independent of time of the day or occupancy of the space.

As a first step towards sustainable lighting design, all luminaires ought to be dimmable. It is understood that underground workspaces must be lit up at all times for safety and personal comfort purposes. The instantenous change from total darkness to light may not be a pleasant experience to the majority of us. The advantage of dimmable lights in the context of underground workspaces is that when luminaires remain at 20% of their total light intensity, then it translates into 80% of electricity being saved, while the space is softly lit. This energy saving pre-set could be activated when the space is not in use.

Secondly, the use of energy efficient luminaires that offer low energy input and high luminal output.

Thirdly, matching number of required luminaires and quanlity of light to specific functions in the space should guarantee a more efficient use of lighting. For example, using direct task lighting when writing offers visual comfort in a more efficient way than using high level of general lighting.

Lastly, the use of timers and positioning occupancy sensors strategically in the space could help conserve the energy.

DISCUSSION

As set out in the main research question, the original quest of this thesis was to study the ways in which future users of the deep underground workspace may benefit from adaptive and intelligent lighting in their day-to-day work activities. This thesis studies the dynamic relationship between the physical configuration of an underground workspace and adaptive and intelligent lighting technology.

As a graduate in architecture with a keen interest in lighting design, I identified two very distinct aspects in this work. On the one hand, lighting affects our perception of space. On the other hand, architectural lighting design coupled with adaptive and intelligent technologies can offer effective solutions to the physiological and psychological requirements of users.

The production of detailed narrative descriptions for each scenario supports a robust conceptual framework for the design of adaptive and intelligent lighting for Retka and Lab 2. The process of creating scenarios from a user experience point of view has provided me with orientation to produce a variety of design solutions fit for an adaptive and intelligent lighting environment. Scenario making is a way to systematically explore a wide range of design possibilities. I firstly identified the key elements that would be present in all scenarios and later classified them into a chart. The exploration of different combinations of those elements occurred at a second stage. The third and last stage consisted of developing the stories that would be based on those combinations.

In generalising ideas behind the design implementation of an adaptive and intelligent lighting environment for Retka and Lab 2, I developed four design themes which I consider to be implicit in every scenario. These are in support of *circadian rhythm*, *activity* and *interaction* as well as considering *energy consumption*. The purpose was to develop optimal lighting strategies that would offer increased energy efficiency in lighting and versatily of the luminaires, such as colour temperature and light intensity adjustments with respect to activity, personal preference and sleep-wake cycle of users.

The overall aim of this thesis is to provide lighting design implementation ideas for the future use of the deep underground workspaces of Retka and Lab 2. Also, it lays out the terms of reference for future research testing in lighting of underground workspaces. Finally, it re-evaluates the role of lighting in workspaces with nil exposure to natural light, in which functional and aesthetic aspects have been addressed in a balanced way.

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